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FRÉDÉRIC CHOPIN: THE MAN AND THE ARTIST

By ARTHUR HEDLEY
Hon. Secretary of the British Chopin Committee, 1960

Weekly Evening Meeting, Friday 25th November, 1960

L. B. W. Jolley, M.A., M.I.E.E.
Vice-President in the Chair

THE year 1960 has brought round the 150th anniversary of the birth of Frédéric Chopin, and the occasion has been marked by impressive commemorations in Poland and France—Chopin's two *patries*—where official bodies and private music lovers vied with each other in honouring the memory of a great artist and patriot. We in this country have no other claim to figure in such celebrations than that which is justified by the great affection and interest which the British public has constantly shown for this unique musician whose work and personality continue to exercise an extraordinary fascination. But although Poland and France were the stage on which his life-story was played out, the fact remains that it was England that gave to the world the first serious biography of Chopin, the first uniform edition of his works, and has provided one of the main sources for the dissemination of his music by means of the gramophone.

Chopin only visited these islands twice—for a fortnight in 1837, and for seven months during the summer and autumn of 1848—but those visits represented occasions of the greatest interest in his almost uneventful life, and they offer a theme for unusually fascinating study. One thinks of Chopin spending the last eighteen years of his existence in France, in extreme seclusion, with only the episode of his visit to Majorca with George Sand coming to interrupt the regular routine of his days. Long years of utter quiet: Paris—the summer months at George Sand's house at Nohant—Paris again. But in 1848, the "year of revolutions", a great social upheaval threw Chopin's tranquil life into disorder. To remain in Paris might mean to starve, for the revolution which ruined the monarchy and aristocracy also brought to an end Chopin's means of earning his living by teaching the daughters of the noble families. And so he came to London, on the day before Good Friday 1848. For a man in his wretched state of

health, and for one of such a reserved and aristocratic nature, it was a leap into the unknown.

The following months in London and Scotland had their few gleams of light, but these were quickly extinguished by depression and the sense of impending doom; and as we meet here on a November evening we may allow out minds to go back to such another November evening in 1848 when, a few yards down the street in which the Royal Institution stands, we might have seen a closed carriage pass, bringing home to his lodging at 4 St. James's Place (Plate I) the "Poet of the Piano" who had, for the last time in his life, given a public audience (at the Guildhall) the rare pleasure of hearing his incomparable performance.

The Royal Institution stands at the very heart of "Chopin's London", and it is impossible for a music lover to be in this part of the town without thinking of that slender, elegant figure continually moving about here during the high season of 1848, paying calls and doing his best to arrange the details of the two fashionable private concerts without which he might have found himself almost penniless. On his arrival he had spent a day or two at 10 Bentinck Street, but as that was too far from the real centre of fashion he moved to 48 Dover Street and remained there until his departure for Scotland.

The exhibition in the Library contains a characteristic letter from this address, written on small elegant paper bearing Chopin's personal crest, and its contents illuminate the composer's strange, almost macabre, mode of life at this time. Can one indeed imagine a more violent contrast than that presented by the spectacle of a man dying of consumption and yet forced to keep up a feverish, exhausting and frightening struggle to achieve success in the glittering and inaccessible circles of the highest society? He writes "I am not used to this London air, and this life of visits, dinners and *soirées* is very hard on me . . . I am now acquainted with a host of Ladies, whose names go in one ear and out the other as soon as they are mentioned . . . I have played at the Duchess of Sutherland's (*at what is now called Lancaster House*) in the presence of the Queen, Prince Albert, Wellington and all the cream of the Garter crowd . . . My lodging alone costs me ten guineas a week (*equal to at least sixty guineas of our money!*), but I have a large drawing-room with three grand pianos . . . I

4 St. James's Place where Chopin spent his last weeks in London, 1848. His rooms were on the first floor, with balcony, of what is now a club.

PLATE I

avoid all the big public concerts and I think I shall give a concert in some fashionable drawing-room, limited to 150–200 people." In the Library can also be seen the indispensable accompaniments to this dazzling existence behind whose façade a tragedy was being played out—the diamond cuff-links, the exquisite ivory comb, the luxurious silk waistcoat and so forth. Yet Chopin was defeated in one of his aims—to play at Buckingham Palace. He was on the point of realising it when one of the Queen's aunts, the Princess Sophia, a survivor from the days of George III, died, and the Court went into mourning. So he had to content himself with private concerts at 99 Eaton Place and 2 St. James's Square, which brought in the modern equivalent of about £2,000.

History presents us with the strangest coincidences! It will be remembered that in July 1848 Charlotte and Anne Brontë came up to London to reveal the secret of Currer, Ellis and Acton Bell. They were taken to the opera, and Charlotte noted, without resentment, that the elegant ladies and gentlemen looked somewhat superciliously at the two provincial visitors in their inappropriate and dowdy clothes. One wonders whether Chopin, who was present that evening, cast a questioning glance at the author of *Jane Eyre!* And did he realise, when Sir James Clark came to visit him and give him useless advice, that this same doctor had attended a young man named John Keats as he lay dying of consumption in Rome in 1821?

During his stay in London Chopin met everyone of note in the literary and artistic worlds—Dickens, Carlyle (whom he visited in Chelsea), Lady Byron, Jenny Lind, the celebrated Mrs. Grote ("How do you find Mrs. Grote?"—"I find her grotesque!")—and on everyone he made the same impression: "a noble and suffering soul", as Carlyle said. And when he sat down to play there was not a listener who did not recognise at once that he was in the presence of a uniquely poetic personality, an artist who by the simple perfection of his playing could convey to his hearers something of the divine inspiration that filled his heart and mind.

The early morning of Saturday, 5th August, found Chopin on platform 6 at Euston, taking the train for Edinburgh. Of his travels in Scotland this is not the place to speak, but there will be seen in the Library exhibition a letter from Johnstone Castle

near Glasgow which reveals the fears that haunted him. He played in Glasgow on September 27th and in Edinburgh on October 4th, earning in each case, as he himself says "A little success . . . a little money." But it could not last; and at the beginning of November he returned to a small dwelling only a short distance away from the Royal Institution. (One may add in passing that it is highly probable that Chopin visited the Institution: he had friends who were Members, and his own brother-in-law in Warsaw liked to be kept informed of anything of interest in the scientific world). At St. James's Place he spent the most miserable three weeks of his life, leaving the house only once, to play at the Guildhall at a concert and ball given in aid of Polish refugees. The London fogs made his life a torment and it was with inexpressible relief that he made his escape on November 23rd. Chopin left because he was driven away by the *climate:* his letters show that he had met with nothing but kindness and sympathy from his British admirers, and that he had been received as someone who was clearly far above the ordinary run of visiting pianists. Jane Welsh Carlyle was one of those who succeeded in expressing what scores of Chopin's English friends felt, and her words may serve as an epilogue to his second and final visit to these shores: "I prefer his music to all others, for it is not a specimen of art offered to general admiration . . . it is rather the reflection of part of his soul and a fragment of his life, lavished on those who have ears to hear and a heart to understand. I think that each one of his compositions must have taken away from the number of the days of his allotted span. Oh, how I wish he understood English! How I wish I could open my heart to him!"

When Chopin died on October 17th 1849 he left behind a relatively small but most precious legacy of enchanting music, one which may be fittingly compared with the modest but irreplaceable achievement of John Keats. Both men died before they had produced more than a fraction of what it was in them to perform; yet whereas Keats vanished almost unknown save to a small band of faithful friends, Chopin had attained a fame which the passage of time has not dimmed. His music was the expression of a closely concentrated and withdrawn personality, concerned with its own intimate experiences and the theme of the past glories, present shame and future hopes of his native Poland. His

Original manuscript of Chopin's Nocturne in C sharp minor.

PLATE II

gaze travelled round a strictly limited horizon and his world has little of the wide universality and comprehensive humanity of Beethoven. But in the midst of all his limitations he exercises a subtle and potent magic: he has the secret of the great poets of all ages—"Heart speaks to heart". And with the intensest personal feeling he combines an unfailing instinct for aristocratic and classical purity in the actual form of his music. It is this union of poetic warmth and fastidious workmanship that has allowed his work to survive while so many of his contemporaries have sunk into oblivion. As one contemplates in the Library exhibition the firm but delicate handwriting of his manuscripts one becomes aware of this dual quality of strength and refinement. The unending search for perfection becomes visible—the anxious alterations and hesitations show the artist's struggle with his material, especially in his last Nocturne in E major, the manuscript of which lies before me. But as this discourse ends the written notes blossom into the poetry of sound; and with this ultimate lyrical utterance Music—Chopin's real native tongue—is given the chance to say those things which no words of speech can ever hope to convey.

The following musical illustrations were performed from the original manuscripts by Madame Natalia Karp:

Nocturne in C sharp minor (Plate II)
Studies in F minor and A flat
Polonaise in B flat
Nocturne in E major
Fantaisie-Impromptu, together with Preludes, Waltzes and the Ballade in A flat.

EXHIBITS IN THE LIBRARY

A display of Chopin's original music manuscripts and a selection of his letters; his silk dress waistcoat, ivory comb, writing desk and fragment of his inlaid bureau; portraits and pictures of his home and events in his life, arranged by *Mr. Arthur Hedley from his personal collection.*

ROCKET ASTRONOMY

By R. L. F. BOYD, Ph.D.
Reader in Physics, University College, London

Weekly Evening Meeting, Friday 9th December, 1960

R. Holroyd, M.Sc., Ph.D., F.R.S.
Vice-President, in the Chair

THE use of rocket propulsion to make it possible to carry scientific instruments to very great heights has introduced a new branch of science to the world. Space research is distinguished from other science, not primarily by its subject matter but by its experimental method; for by general usage it is taken to mean research carried out by means of rockets. There is very much in geophysics and astronomy that is still studied and will continue to be studied by methods which were in use before the advent of space research. These studies will be extended using ground based techniques even though it is now possible to carry instruments through the atmosphere and its outer fringes, to the moon and the vicinity of the planets.

In some work, however, ground based observations are becoming supplementary to space observations. They are of value in keeping a continual watch on phenomena which for economic or reasons of practicability can only be glimpsed from a rocket or satellite. The rocket measurements in their turn, have improved our understanding and ability to interpret the terrestrial data.

Nowhere has the impact of space science been greater than on the most ancient of the pure sciences—Astronomy. For five thousand years all our information on the Cosmos came in waves of light caught by the quarter inch pupil of the human eye. For the last five hundred years the eye has been assisted and its effective aperture increased by the use of mirrors and lenses, and with the increased light gathering power came also improved precision of measurement and the use of spectrometers to analyse the quality of the light. For nearly a hundred years use has been made of photographic emulsions, then later of photo and thermoelectric devices and finally of radio receivers to detect the radiations from space. Now within the last five years the study of astronomy has been carried out into space itself and by using

rockets it has become possible to make experiments there instead of here.

Rocket propulsion has affected experimental astronomy in three main ways. Firstly, new astronomical objects—artificial satellites, planets, comets and meteors can now be established by human effort. Secondly, instruments can be sent to the moon and (soon no doubt) to the planets and out into interplanetary space to study these regions at close quarters. Thirdly, telescopes can now be carried out beyond the atmosphere of the Earth so that the classical limitations imposed by the properties of the atmosphere on traditional astronomy may be overcome.

The prowess of the rocket engineers has been given a global demonstration in the creation of such celestial artefacts as Sputnik II and EchoI . These artificial satellites were bright objects in the night sky, for all to see. From a study of their motion and that of other artificial satellites a surprising amount of information can be obtained, even when, as in the case of Echo I, no radio telemetry is employed.

Two influences exert a primary control on the motion of an artificial satellite. From a study of the motion we can learn about these influences. The position of the orbit in the sky does not remain fixed but precesses due to assymetries in the gravitational field of the Earth. To understand this precessional motion we can think of the wobble of a spinning top. Such a wobble arises because the top is a gyroscope. Since it is spinning rapidly the tendency to topple over is converted into a precession so that its spin axis describes a conical motion. The movement of a satellite in its orbit about the Earth can be likened to the spin of a top. Because the Earth is greater in diameter at the equator than at the poles, the satellite path will be subject to a gravitational pull tending to bring it into the equatorial plane. By the same laws of mechanics that govern the motion of the top, however, this pull actually results in a precession, a conical motion, of the axis of the orbit about the polar axis. The rate of this precession, which is typically a few degrees a day, provides a measure of the size of the equatorial bulge. Measurements made by such a study of satellite orbits suggest that the equatorial diameter of the Earth is in fact a few hundred feet less than it was formerly thought to be.

Not quite so clearly in the domain of astronomy, but neverthe-

less strongly affecting the motion of a satellite, is the atmospheric drag. The nearer a satellite approaches the Earth, the denser the air through which it moves, and the more rapidly it will lose height. As the size of the orbit decreases the satellite gains speed. Moreover, it moves on a smaller orbit so that both because of the increasing speed and the shorter path it takes less time to complete a circuit. Almost all of our best data on the density of the outer fringes of our atmosphere comes from measurements of the rate of decrease in the period required for artificial satellites to complete an orbit.

Of course, for measurements of this kind the path of the satellite in the heavens must be tracked very accurately. For this purpose use is frequently made of the radio beacon in the vehicle whose position can be found by radio direction finding methods. In the absence of a radio beacon operating in the satellite, or when the most precise data is required, the techniques of optical astronomy are employed. The satellite may be photographed while it is illuminated by the sunlight though the sky is dark because the sun is still below the horizon. Alternatively, the motion of the image of the satellite in the focal plane of the telescope may be detected and recorded photoelectrically. In either case, reference is made to the fixed stars to establish the direction of the telescope precisely.

For a number of practical reasons, attention both in scientific and lay circles has been focussed on artificial satellites, but comets, planets and meteors have also been created, and in each case the work has been of astronomical significance. The tail of a comet is a mass of glowing gas, fluorescing in the sunlight. On each of their moon shots the Russians have created an artificial comet by ejecting just such a cloud of sodium vapour. This was done to provide a mark on the path of the vehicle, at a great distance from the Earth, which could be photographed precisely so as to give accurate data on the path.

Artificial planets in orbit round the sun have resulted from vehicles fired beyond the control of the Earth's gravity by both the Americans and the Russians. The latter have been rather unfortunate with their radio telemetry link so that contact has been lost early, but the Americans maintained contact with Pioneer V to a distance exceeding twenty million miles and from

it they learnt how the Earth's magnetic field dwindles away, and becomes replaced by fields due to electric currents in the rarified interplanetary medium. Important data on the motion of this medium and on the streams of charged particles shot out from the Sun were also obtained.

It is to be expected that experiments with artificial planets will provide situations in which the propagation of gravity and the phenomena of general relativity may be studied. Natural astronomical situations providing for studies of this kind are rather rare.

Meteors, those tiny particles of interplanetary material we see at night as the glowing streak of a shooting star, are of interest both as samples of celestial material and as a means of studying the upper atmosphere where they meet their fiery end. One problem in connection with understanding their interaction with the atmosphere has been uncertainty about their composition. It is now possible to eject artificial meteors from rocket vehicles, indeed most satellites re-entering the dense part of the atmosphere become incandescent like meteors. This makes it possible to study the meteor-like behaviour of bodies of known composition. Amongst the most important facets of this behaviour are the mechanism by which they become luminous and the mechanism by which they produce trails capable of reflecting radio waves.

So far, we have been discussing artificially created celestial phenomena. Now we must turn our attention to laboratories in the skies. First there are the deep space probes—vehicles sent out with their load of scientific instruments to the neighbourhood of the moon and the planets. The problem involved in guiding a rocket to Mars or Venus and in establishing an adequate radio link is very great indeed, but even so it cannot be long before a start is made in this kind of study. We can expect analyses of the atmospheres of these neighbouring worlds to be amongst the earlier experiments to be carried out and no doubt a careful research will be conducted to see if there are any organic substances suggesting the presence of life.

The Moon is a much easier object for study. A good start has been made by the Russian photography of the far side. For this a jet stabilised vehicle was used controlled in such a way by its own

observations of the Sun and the Moon that its two cameras faced the, as yet, unseen side. The problem of transmitting so detailed a picture over the distance from the Moon to the Earth was solved by automatically developing the film inside the vehicle and by delaying its facsimile transmission by radio until the Lunik was once again in the vicinity of the Earth.

Another important observation has been the measurement of the lunar magnetic field. This turns out to be less than one quarter per cent of the value of the Earth's field. It seems very probable that this implies that unlike the Earth, the Moon has no fluid core for it is thought to be motions in the fluid core of the Earth that produce the Earth's field.

Very likely the next stage in deep space probing will involve landing instruments on the Moon which can send back data about the surface and the underlying layers and later instruments which can move about so that we can explore the varying character of the so-called seas, the mountains, the rays and craters. Eventually, we can expect men to accompany the instruments but there is no doubt that both on the Moon and the planets much can be explored and much learnt with instruments alone, without the hazard of sending a man, maintaining him in good condition physically and psychologically and bringing him back safely.

Long before man sets foot on the Moon another exciting development in rocket astonomy that is now only just beginning will be making an important contribution to the science. This development is astronomy by means of telescopes and other instruments carried above the atmosphere on satellites circling the Earth.

Optical astronomy from the ground suffers from three classical limitations due to the presence of the Earth's atmosphere, while similar phenomena in the ionosphere assail radio astronomy. The first of these problems arises from the ability of the atmosphere to scatter light. It is of course, the scattering of sunlight by the molecules of the air which gives rise to the blue colour of the sky. At night, even when the sunlight is completely screened from the sky, moonshine and starlight are scattered and, often worse still, light from neighbouring towns illuminates the sky, so that there is a definite limit to the faintness of a detectable celestial object.

For astronomy from a satellite orbiting four hundred miles above the Earth this problem would no longer arise since virtually all the atmosphere would be below the satellite. Providing a suitable satellite observatory can be launched successfuly, it should thus be possible to look for fainter and so sometimes more distant objects. In particular, perhaps in this way it will be possible to see extra-galactic nebulae at greater distances than at present, away out near the bounds of our visible universe, and by studying their number to see whether they are thinning out. The answer to this question could help us to decide between the rival theories of cataclysmic versus continuous creation.

The second limitation to classical astronomy arises from the refraction, that is to say bending, of light by density irregularities in the atmosphere, which gives rise to stellar twinkling. As the wind movements of the upper air bring these irregularities between the star and the observer the light is slightly deflected and alternately focussed and defocussed so that the brilliance and position of the star appears to vary. This makes accurate photography of position and precise resolution of close objects very difficult. There can be little doubt that astronomy from satellites will ultimately give better position data and resolution, although many engineering problems associated with figuring the optical surfaces and keeping them pointing accurately in the right direction, have first to be overcome.

It may be, however, that one of the most important problems awaiting better astronomical *seeing*, that of obtaining high definition pictures of the planets, especially Mars, will in the case of the latter at any rate, be solved first by sending a vehicle to that vicinity.

Perhaps the most severe limitation imposed on astronomy by our atmosphere is due to its ability to absorb all electromagnetic radiation over the major part of the spectra of celestial objects.

Imagine the whole range of electromagnetic waves to be represented by a piano keyboard, and further, imagine that the frequency of the waves represented by any given note is ten times greater than for the same note an octave lower, instead of just twice as great as for the sound waves from an actual piano. Radiation reaches the upper atmosphere in amounts which are

probably detectable over twenty or so decades (i.e., scales of ten "octaves" of the kind we have just defined). The whole range of visual light is represented by about three notes. Photographic and photoelectric astronomy from the ground can extend this range a little especially on the long wave, or infra-red, side. A further extension towards the long wave end of the spectrum can be obtained by carrying the equipment aloft in a balloon.

Radio waves such as are detected in radio astronomy cover about three decades. Of the remaining decades almost nothing can be detected from the ground. Yet it is known that the Sun and stars radiate strongly in many of these inaccessible regions of the spectrum. In the case of the Sun, for example, ultra-violet light and X-rays are responsible for the existence and behaviour of the Earth's ionosphere. Furthermore, in the X-ray region especially, the sunlight varies in intensity from time to time by many orders of magnitude and a study of these variations and their association with the occurrence of storms on the Sun is leading to a better understanding of the solar atmosphere. It will not be long before similar studies will reveal for the first time the similarities and differences between the atmosphere of the various classes of star and that of our Sun.

Already, by mounting small telescopes on rockets and allowing them to scan the sky as they roll and precess on their trajectories, a glimpse is being obtained of the sky in ultra-violet light. Very soon these relatively crude experiments will give place to complete observatories in orbit with reflecting telescopes of twenty or thirty inches aperture.

Stabilisation by gas jets or gyroscopes will point the telescope with fantastic precision in the required direction, while the direction itself will be dictated by an internal programme or selected as a result of a radio transmitted command from an astronomer on duty below. Out in space the *seeing* will be unaffected by the atmosphere, while the weightless telescope will not be subject to bearing friction and earth tremor movements.

It would be unwise to overlook the engineering and indeed, economic problems in Rocket Astronomy and yet there can be no doubt that the rocket is about to usher astronomy into an era as unexpected, as fruitful and as exciting as that introduced by the spectrograph or by the invention of the telescope itself.

ROCKET ASTRONOMY

EXHIBITS IN THE LIBRARY

(*a*) Rocket-borne solar X-ray camera; solar Lyman-Alpha detectors; model of British Skylark rocket; colour photograph of Sunseeker system for Aerobee rocket; diagrams of a proposed X-ray spectroheliograph and Skylark ultra-violet telescope unit; lent by *University College Department of Physics.*

(*b*) Scale model of Saunders-Roe Black Knight research rocket; model of proposed British satellite-launching vehicle; lent by the *Royal Aircraft Establishment, Farnborough.*

A CRUCIAL STAGE IN VERTEBRATE EVOLUTION: FISH TO LAND ANIMAL

By PROFESSOR T. STANLEY WESTOLL,
Ph.D., D.Sc., F.R.S.E., F.R.S.
J. B. Simpson Professor of Geology, King's College (Newcastle-upon Tyne) in the University of Durham

Weekly Evening Meeting, Friday 12th May, 1961

W. E. Schall, B.Sc., F.Inst.P.
Treasurer and Vice-President in the Chair

GENEALOGY is a common enough human interest; those who, like myself, have occupied themselves with fossil vertebrates extend this curiosity enormously into past time. We have long known that man is one of a diversified group known as mammals, and that mammals, birds, reptiles and amphibians are essentially modifications of a generalised vertebrate which would be, among other things, four-legged and air-breathing; the term tetrapod is frequently used for all these creatures. Comparative anatomists and embryologists, before the end of the last century, had made observations and discoveries that indicated with high probability that tetrapods were descended from fishes. Modern tetrapods and modern fishes, as known a century ago, show only slight resemblances. The living lungfishes were not known then, and the living coelacanth, *Latimeria*, was not discovered until 1939; moreover, however fascinating the resemblances to tetrapods shown by these fishes—and the Australian *Epiceratodus* was at first regarded as an aberrant urodele amphibian while Professor J. L. B. Smith has made *Latimeria* familiar to many as "Old Four-Legs"—none can be regarded in any way as a surviving unchanged ancestral type.

When Darwin published "The Origin of Species" in 1859, he headed one of his chapters "On the Imperfection of the Geological Record", and had good cause to lament the paucity of fossil remains linking living groups. The ensuing century has seen a truly remarkable increase in our knowledge of fossil vertebrates and of geological events; we can now place our discoveries in a far more reliable framework of geological history, with increasingly trustworthy estimates of a time-scale based on "radioactive clocks".

If we can now briefly summarise our own remoter genealogy,

mankind is a recent development, within the last million years or so, from large primates; primates can be traced back some 60 million years into the early Cainozoic, where they converge upon insectivores and other eutherian mammals. The earlier history of mammals is only patchily known during the Mesozoic, but at least some forms are known from late Triassic and early Jurassic rocks, some 180 million years old. There can be no doubt that these emerged from one or more of the groups of "mammal-like reptiles" which flourished in Triassic times, and which can be traced back to ancestors in very late Carboniferous times, about 280 million years ago. These early mammal-like reptiles (Fig. 1) converge upon a broadly contemporaneous basal reptilian group, the Cotylosauria, which in turn approach in their structure the Carboniferous members of a group known as Stegocephalia, which must be regarded as Amphibia. Until fairly recently the earliest known Stegocephalia came from well up in the Lower Carboniferous, which on Professor Holmes' newly-revised (1959) time-scale, which I use throughout, means about 325 million years ago. The fossil Amphibia, however, were already diversified by this time, and recent discoveries from the Upper Devonian and Lower Carboniferous (about 360–340 million years old) will be discussed. But nearly 40 years ago Professor D. M. S. Watson was able to draw very significant conclusions from the fossil Stegocephalia known to him, and to show more clearly than earlier workers that the strongest resemblances of these early tetrapods were to fishes of the groups Crossopterygii and Dipnoi, which flourished in Devonian and Carboniferous times.

Fishes, like tetrapods, have become diversified and modified and have suffered many casualties with the passage of time (Fig. 1). This is why modern fishes—even lungfishes (Dipnoi) and *Latimeria* (Crossopterygii)—give so few direct clues to the ancestry of tetrapods. But we can now illuminate from fossil remains the crucial stage of transformation of fish ancestors to tetrapod descendents, with legs instead of fins, capable of air-breathing and movement on land. Even though the early tetrapods were certainly amphibians spending much of their time in water, the derivation from them of reptiles poses very few problems; the real evolutionary novelty is the tetrapod structure, and the crucial problem is its derivation from fish ancestors.

THE EARLY BRANCHING OF THE VERTEBRATES

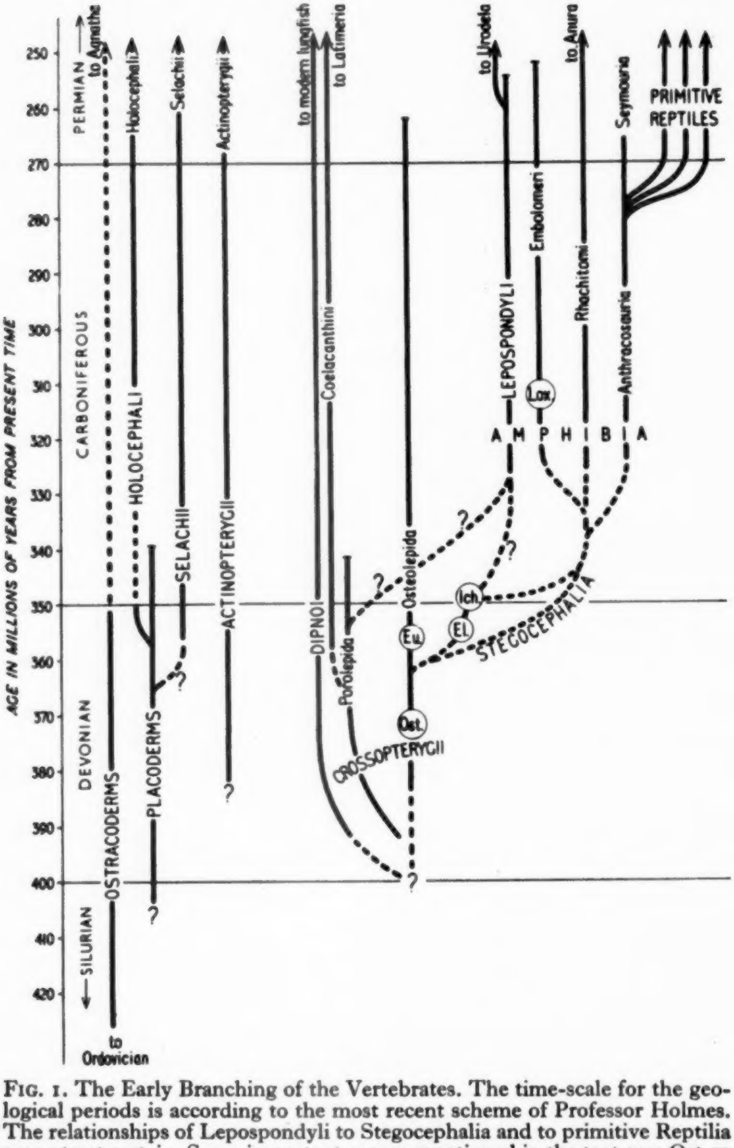

FIG. 1. The Early Branching of the Vertebrates. The time-scale for the geological periods is according to the most recent scheme of Professor Holmes. The relationships of Lepospondyli to Stegocephalia and to primitive Reptilia are not yet certain. Some important genera mentioned in the text are: Ost.=*Osteolepis;* Eu.=*Eusthenopteron;* El.=*Elpistostege;* Ich.=*Ichthyostega;* Lox.=*Loxomma.*

It is well at this stage to realise that the discovery of fossil remains is only part of the story. The techniques for their proper investigation and study have also progressed remarkably. There are still very many discoveries to be made, and one can confidently predict many interesting finds from Devonian and Carboniferous rocks that will add to our knowledge. Some of these will result from deliberate patient search based on geological knowledge, some by fortunate chance—the gift most desired by even the most active palaeontologists is serendipity! But, once collected, these fossils yield their information only to those able to use with skill a variety of methods of removing rock from bone and scale, and to apply the most exacting methods of comparative anatomy to their study. Our present knowledge is directly due to such workers as Stensiö, Säve-Söderbergh and Jarvik in Sweden, D. M. S. Watson and others in Britain, A. S. Romer in the U.S.A., Bystrow in the U.S.S.R., and many others who have developed new techniques and methods of study.

It is now quite clear that we need not look, for the immediate ancestors of tetrapods, beyond the confines of two groups of fossil fishes. These are: (*a*) the Dipnoi or lungfishes, which range from the lower Devonian to the present day and have been regarded by some as the probable ancestors of the amphibians known as Urodela (newts, salamanders, etc); and (*b*), the Crossopterygii, which may for convenience be regarded as comprising three main sections (Fig. 1). These are

(i) the Osteolepiformes, ranging from (lower or) middle Devonian to the lower Permian;

(ii) the Porolepiformes, lower Devonian giving rise to later Devonian (and ? lower Carboniferous) genera such as *Holoptychius*; and

(iii) the Coelacanthini, probably derived from the porolepid-holoptychiid stock and ranging from about the top of the middle Devonian to the present-day *Latimeria*.

All other groups of fishes—and there are many—existing in Devonian times may be ruled out of consideration; none but those mentioned show combinations of structural features which could possibly give rise to the special characteristics of tetrapods.

In the last few decades our knowledge of fossil Dipnoi has greatly increased. The Devonian members of the group are al-

ready greatly specialised, and it seems now very highly unlikely that they include ancestors of any tetrapods. But many workers in comparatively recent times have supposed that the urodele amphibia may be descended from them, on the basis of comparative anatomy of palate and limb and of some features of embry-

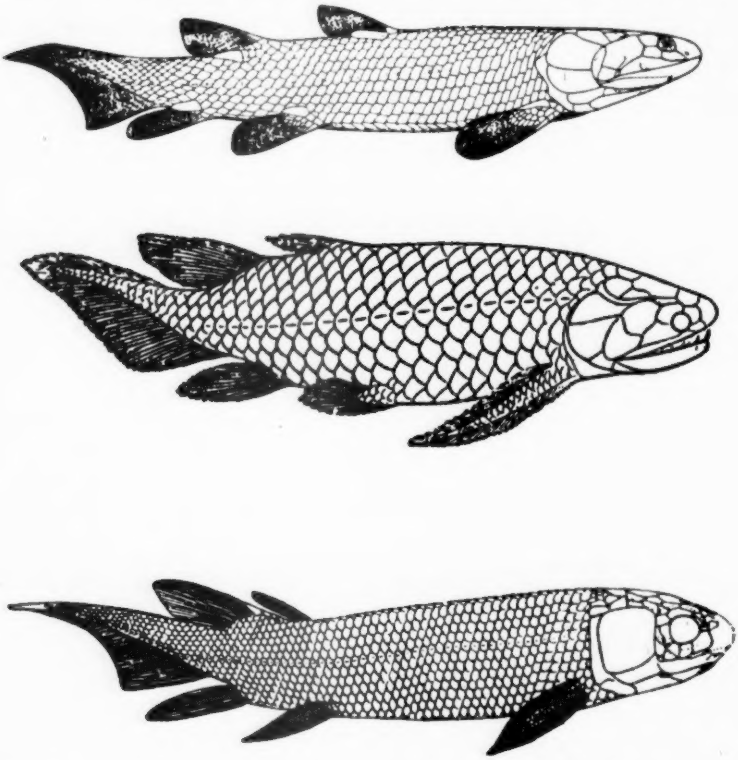

FIG. 2. Devonian fishes of groups considered by various workers to be related to tetrapod ancestry. *Above*, the osteolepid crossopterygian *Osteolepis* (from Jarvik); *middle*, the porolepid crossopterygian *Holoptychius* (from Traquair); *below*, the lung fish (dipnoan) *Dipterus* (from Watson).

ology of living forms. The evidence of the fossils seems decisive and we may leave them on one side, remembering only that those characters once thought to be of significance in the origin of tetrapods may well include features of very long standing in this group, which rapidly converges backwards upon the Crossopterygii in the Lower Devonian.

The Crossopterygii have their three main sections well developed by late Devonian times. Of these, the coelacanths have a remarkable history in some ways resembling that of the lungfishes. The living *Latimeria* differs remarkably little in most of its skeletal anatomy from all post-Devonian members of the group; but some fossils from the Upper Devonian are a little different, and some specimens I have from the lower part of the Upper Devonian of Canada show decisively that they were derived from the porolepid-holoptychiid group and were then rapidly converging backwards upon that stock.

Again, without going into the technical details, the coelacanths are, even at this early stage in their evolution, far too specialised in their anatomy to be ancestral to any tetrapods. "Old Four-Legs" *Latimeria* has, of course, inherited many structural features common to other Crossopterygii, and is of the utmost interest as the only living crossopterygian fish; but it can in no way be regarded as a "missing link".

We are left with the osteolepids and holoptychiids in the middle and upper, and *Porolepis* in the lower Devonian (Fig. 2). It has seemed most likely for some 50 years that these fishes were important in the search for tetrapod ancestry. Watson in 1926 added very greatly to this likelihood; by the time the writer reviewed the position in 1943 it was a near-certainty; after a similar interval the accumulated evidence is overwhelming. And it is increasingly clear that all but a small minority of tetrapods show the most decisive evidence for an osteolepid ancestry; only for urodele amphibians does the possibility remain of a porolepid-holoptychiid origin. We may for the moment disregard this exception.

When in 1926 Watson surveyed this problem, the earliest known fossil amphibians were of Carboniferous age. Recent revision of the geological evidence shows that the fossil amphibians on which he placed most reliance are from strata of middle and upper Carboniferous age; other creatures he described later (1929) include fossils from well up in the Lower Carboniferous. He made out a most persuasive case for regarding certain large Stegocephalia, which he called the Embolomeri, as very primitive amphibians, and compared their anatomy with that of osteolepid fishes in sufficient detail to prove that the latter were unique among the known fossil fishes in many detailed resemblances to

primitive tetrapods. Since that time very important new discoveries have helped to fill the gap; at the same time new interpretations of the structure of the crossopterygians, and anatomical studies of unprecedented detail on these fossils, have proceeded apace.

The most startling of the new discoveries was first made known in 1932, when a brilliant young Swedish palaeontologist, Säve-Söderbergh, published the first account of fossil stegocephalians from East Greenland. These animals, known at first only from skulls, were placed in two new genera, *Ichthyostega* (Fig. 3) and *Ichthyostegopsis*, and were found in strata then regarded as Upper Devonian, but which most stratigraphers would now place in the lower part of the Lower Carboniferous. A great deal of further material has since been collected, including excellent remains of the skeleton, which has been partly described, since Säve-Söderbergh's untimely death, by Dr. Erik Jarvik. Another kind of stegocephalian from the same rocks has also been discovered. *Ichthyostega* shows the most astonishing admixture of features characteristic of crossopterygians and of stegocephalians; and may be shortly described as a very primitive tetrapod retaining many vestigial characteristics of its fish ancestors. But it raises many new problems which we shall shortly review.

One of these concerns the bones of the skull. In all primitive tetrapods and in all primitive bony fishes the skull is made up of two very easily distinguishable kinds of component. One is known as cartilage which may be partly or wholly replaced by cartilage bone; the other is known as dermal bone. The cartilage and cartilage-bone form the endoskeleton, which surrounds the brain, and the nasal and inner ear capsules, to form what is usually called the "brain-case". The gill-arches and the jaws also include cartilage elements more or less ossified—in the upper jaw the palato-quadrate, in the lower jaw Meckel's cartilage. The dermal bones are formed in skin, invest the outside of the skull-roof, cheeks, lower jaws, etc., and also form important elements lining the mouth-cavity (and often provided with teeth), applied to the base of the brain-case, to the palato-quadrate, to the inside of Meckel's cartilage, and to the inside of the other visceral arches. In bony fishes the opercular folds which cover the gills are also provided with various dermal bones. All the fishes and early

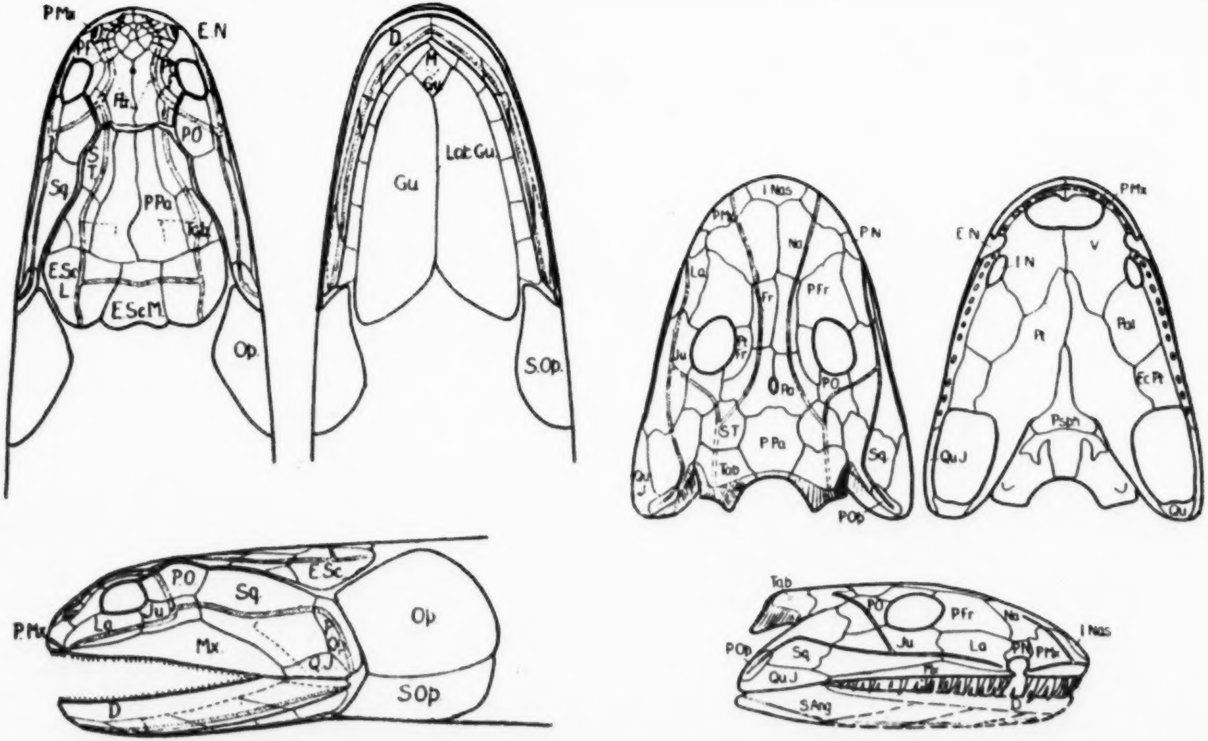

FIG. 3. Skulls of *Osteolepis* (*left*) and *Ichthyostega* (*right*) (from Westoll). The skull-roof bones of *Osteolepis* are labelled as their homologues in *Ichthyostega*. The view of the skull from beneath in *Osteolipis* shows lower jaws and gill-covers in place; that of *Ichthyostega* is of the palate alone.

tetrapods we shall deal with had therefore a kind of stiff mask made of bony armour occupying almost the whole thickness of the skin, and soft mobile tissue was confined to such things as eyelids, the membranes around the nostrils, the labial folds at the gape of the jaws, and any necessary lines of flexibility. Even a codfish has a range of expression beyond these ancestors of ours, and the mobility of face of a mammal is a comparatively recent acquisition.

In most of the fossils, dermal bones are better preserved and more accessible for study than the endoskeleton, but recent work is giving us an increasingly deep knowledge of both. In this respect I must first commend Jarvik's monumental studies of the osteolepid *Eusthenopteron* and of *Ichthyostega*, both so far published only in part; Romer's studies of both osteolepids and primitive tetrapods; and the work of the late Professor Bystrow, a Russian palaeontologist with a genius for exact and beautiful draughtsmanship.

The names given to the dermal bones are based on the names originally applied in human and mammalian anatomy—nasal, frontal, parietal, maxilla, lachrymal, jugal, etc.—with such additions as have been found necessary. It is possible to trace an almost perfect sequence from man and mammals through mammal-like reptiles to primitive reptiles and amphibians, so that we can at once apply to *Ichthyostega* the standard tetrapod names. In the case of fishes the situation is rather different. Many of the tetrapod names have long been applied to bones of fishes, but living fishes are very remotely connected with living tetrapods, and only a general similarity in arrangement was possible as a guide. Thus when the fossil osteolepids, for example, were first described their bones were named by comparison with other fishes. Before the discovery of *Ichthyostega* the writer had deduced that important errors had crept into this terminology, disguising the real relationships of the skull-roof (Fig. 4). The dermal bones of the cheek and jaws, however, are directly comparable in osteolepids and tetrapods. The discovery of *Ichthyostega* led Säve-Söderbergh to a rather radical revision of skull-roof homologies. Curiously enough, instead of modifying the terminology of the *fish* skull to make it conform with the standard tetrapod terminology, he used the erroneous homologies of the fish skull

as his basis for new names applied to tetrapods, which led to magnificent confusion. He also found it necessary to suppose that both groups were descended from a common ancestor with many bones which had fused in different ways to produce different patterns of larger bones. My own conclusions were even more

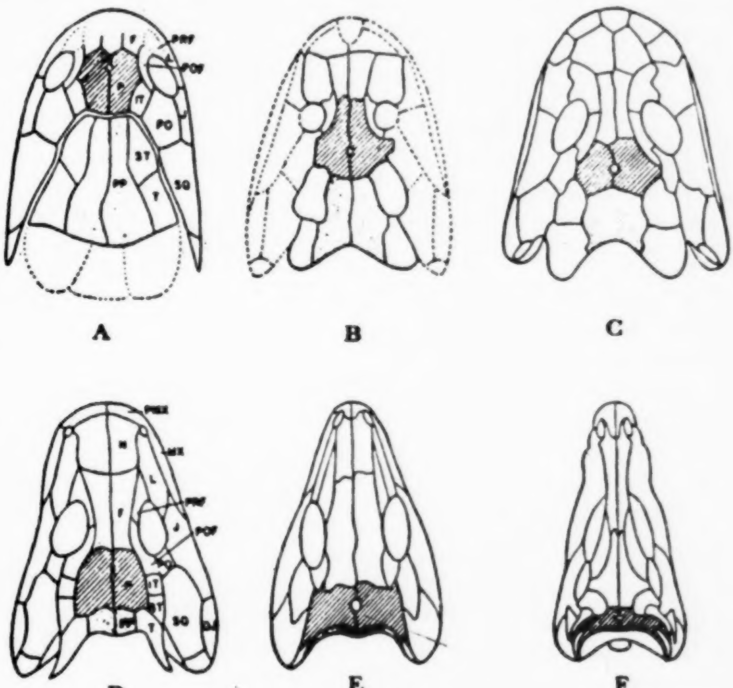

FIG. 4. Skull-roofs of (A) an Osteolepid, (B) *Elpistostege*, (C) *Ichthyostega*, (D) a Carboniferous stegocephalian, (E) a cotylosaurian reptile, (F) a primitive mammal-like reptile (from Romer). The parietals are obliquely lined. The differences in proportions, which led to difficulties in homologising bones as between (A) and (D-F), are clearly shown.

radical, but simpler in their effect, and were strongly confirmed by the discovery by Dr. Graham Smith and myself of a partial skull-roof from the Upper Devonian of Canada (Westoll, 1938). This animal, *Elpistostege*, is in this respect an almost perfect bridge between its contemporary osteolepid *Eusthenopteron* and the later *Ichthystega*, but we have no information concerning the remainder of the skeleton.

There is an important structural peculiarity of the crossopterygian fishes that might be thought to rule them out of consideration as tetrapod ancestors. This is a transverse division of the brain-case, which must have allowed a certain degree of "give" during catching of prey and mastication. All Crossopterygii show clear indications of this, but adult lungfishes (with the possible exception of the very earliest) do not. Tetrapod adults (with a similar possible exception) also show no evidence of such movement. Yet the embryonic stages of all vertebrates go through a similar condition, the final brain-case being composed of two embryologically separate sections—an anterior part arising as paired trabeculae cranii to which are added the nasal capsules and other structures, and a posterior part arising as paired parachordals to which are added the auditory capsules and other structures. The dermal bones of crossopterygians usually show a marked transverse division so that the skull-roof is composed essentially of two dermal "shields".

Before the discovery of *Ichthyostega* and *Elpistostege* the similar names applied to the dermal bones of the skull-roof in the fishes and tetrapods disguised some very real differences. It is now clear that the names applied to the fishes were systematically wrong, in that many of them were given to the bone next behind the true homologue. Recognition of this fact at once allows an extremely satisfactory correlation of dermal bone and cranial structures, and points to a large-scale change in relative proportions, which, as Romer has indicated, continues into the primitive reptiles. The brain-case shows an identical proportional distortion. However, the bones of the cheek, palate and jaws are practically unaffected except in so far as the palate is changed to accommodate itself to the brain-case. The relative stability of these structures is easy to understand, since the feeding-mechanisms must remain efficient.

We may note here in passing that the teeth of the osteolepid and porolepid-holoptychiid stocks are astonishingly similar to those of the most primitive tetrapods. The maxilla and premaxilla of the upper jaw, and the dentary of the lower jaw, have smaller teeth set in a row and capable of rapid replacement; the vomer, palatine and ectopterygoid bones of the palate, and the coronoid bones of the lower jaw, bear large fangs in a curious way, large

"sockets" carrying two sets of fangs which replace alternately. Finally a general "granular" dentition may be present on other bones lining the mouth cavity. Furthermore the large fangs always, and the smaller teeth sometimes, show a remarkable infolding of the enamal and dentine. This gives a labyrinthine appearance to the cross-section of the tooth, and large Stegocephalia have often been termed "labyrinthodonts". That such conditions occur in our crossopterygians in the Devonian is a most important point. The lungfishes, for example, are already completely specialised for another mode of feeding.

The convincing similarity of the skeleton of the face, palate and jaws throws into strong contrast the fact that no other fishes share these features—not even the lungfishes, and the coelacanths have modified a basically similar structure in an entirely individual way. Moreover, the holoptychiid fishes have the bones of the cheek organised in a characteristic pattern somewhat different from that of *Ichthyostega* and early Stegocephalia. Only the osteolepids have the identical pattern, and, thanks to Dr. Jarvik, an osteolepid genus *Eusthenopteron* is becoming one of the most intimately known of all fossils.

We shall briefly return to the changes in proportion and the rigidity of the skull in another context. Here I briefly refer to two other special features of early tetrapods. The first is that, like all later tetrapods, they have a nasal capsule with three connections to the exterior—an external nostril, an internal nostril, and a lachrymal duct. Among living vertebrates a true internal nostril is almost strictly confined to tetrapods, though lungfishes have modified structures that are more or less similar; even *Latimeria* is not very closely comparable. Jarvik has shown in great detail that *Eusthenopteron*, a fish, already possessed every structure of the nasal region needed for the normal tetrapod. He also considers that slightly different conditions in *Porolepis* more closely resemble those in modern urodele amphibians. The strength of this latter argument has been greatly weakened by Kulczycki (1960).

The second peculiarity of typical tetrapods is the development of a "middle ear", with a cartilage bone known as the stapes playing an important role. The primitive stapes has two proximal "heads"; one lies in the membrane closing the fenestra ovalis

and presumably helps to transmit sound-vibrations to the fluids of the inner ear, and the other is attached to the brain-case above the fenestra. It has long been known on embryological grounds that the stapes must be equated with an element of the hyoid arch of fishes, namely the hyomandibular. Only in the Crossopterygii is the hyomandibular two-headed, with the correct anatomical relations. In *Eusthenopteron* the hyomandibular supports both the jaws and the main bone of the opercular fold. When the operculum was closed, the cavity within must have had interesting resonating properties when affected by sound-vibrations. The possible transition from hyomandibular to stapes has been discussed elsewhere in detail (Westoll, 1943b).

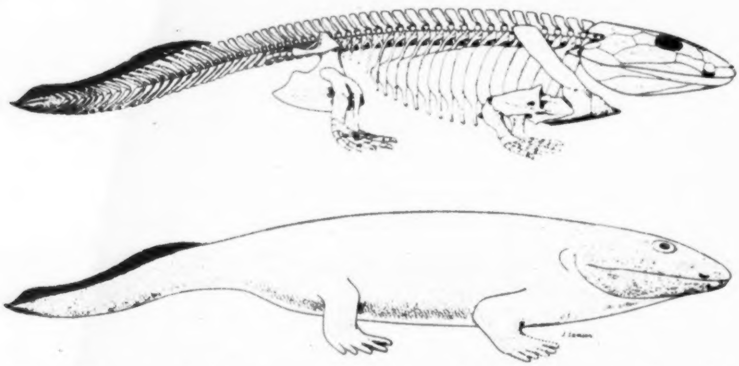

FIG. 5. The very primitive tetrapod *Ichthyostega* from the uppermost Devonian or lower Carboniferous of East Greenland (from Jarvik).

Amphibians, at some stage of development, normally have a fleshy opercular fold, usually lost in the adult. *Ichthyostega* is remarkable in retaining a vestigial bone in the opercular fold. It also, incidentally, retains an element in the cheek, the preopercular, lost in later tetrapods.

Let us now consider the body. It is known that many primitive Amphibia had a more or less newt-like form, and were clearly still "at home" in water. Jarvik has recently shown that *Ichthyostega* (Fig. 5) had a relic of its fish ancestors not retained later, namely, bony fin-rays in the web of the tail-fin. Scales tend to diminish in importance in tetrapods, but many primitive forms retain them. But the obvious new development is walking legs, already well developed in *Ichthyostega*.

The nature of the limbs in early tetrapods is well known, and is the basic pattern from which a great variety of adaptative modifications later developed. If we take the forelimb, the humerus is a bone of remarkable complexity in early tetrapods, succeeded outwards by two bones (ulna and radius), then by a complex of bones forming the wrist (carpals), finally by the metacarpals and phalanges of the hand. There are very few fishes with anything remotely resembling such a structure, but these include lungfishes and crossopterygians. Indeed, the position of the rhipidistian crossopterygians as likely tetrapod ancestors was first made clear by elucidation of fin-structures. Different members of the group show considerable variations. *Eusthenopteron*, for example, has a pectoral fin composed of one element articulating with the primary shoulder-girdle, succeeded by three rather similar diminishing cartilage bones. Each of these four bones (metameres) supports a radial on the leading margin of the fin, and most have a strong process on the opposite (postaxial) side. The whole was provided with strong muscles and covered with scales, which also overlap the bony fin-rays. Another very large American fossil known as *Sauripterus* has more than four metameres and the radials may be jointed and distally bifurcated in series. A specimen of *Eusthenopteron foordi*, beautifully prepared by my assistant Miss Andrews, is exhibited, and shows that the proximal element corresponding to the humerus is remarkably complex, and shows almost every detail required for a primitive tetrapod. The next two elements distally are clearly ulna and radius. There is room for some difference of opinion concerning the exact mode of transition of the outer parts of the fin into the carpus and digits of a tetrapod (see Westoll 1943a). Nevertheless there is no doubt that this rhipidistian type, or one of its modifications, is the only possible ancestral structure for the fore-leg of a primitive tetrapod (Fig. 6). The fin-skeleton of the pelvic fin is similar in type. There is, however, one very striking difference between these fish and even *Ichthysotega*. The endoskeleton shoulder-girdle of the latter is of typical early tetrapod type, with a well-developed scapula and coracoid, and the pelvic girdle is of the tetrapod triradiate type, with the ilium rising to meet the sacral ribs of the axial skeleton. In *Eusthenoptreon* the "primary" pectoral girdle is small, without expanded scapula and coracoid, and strongly

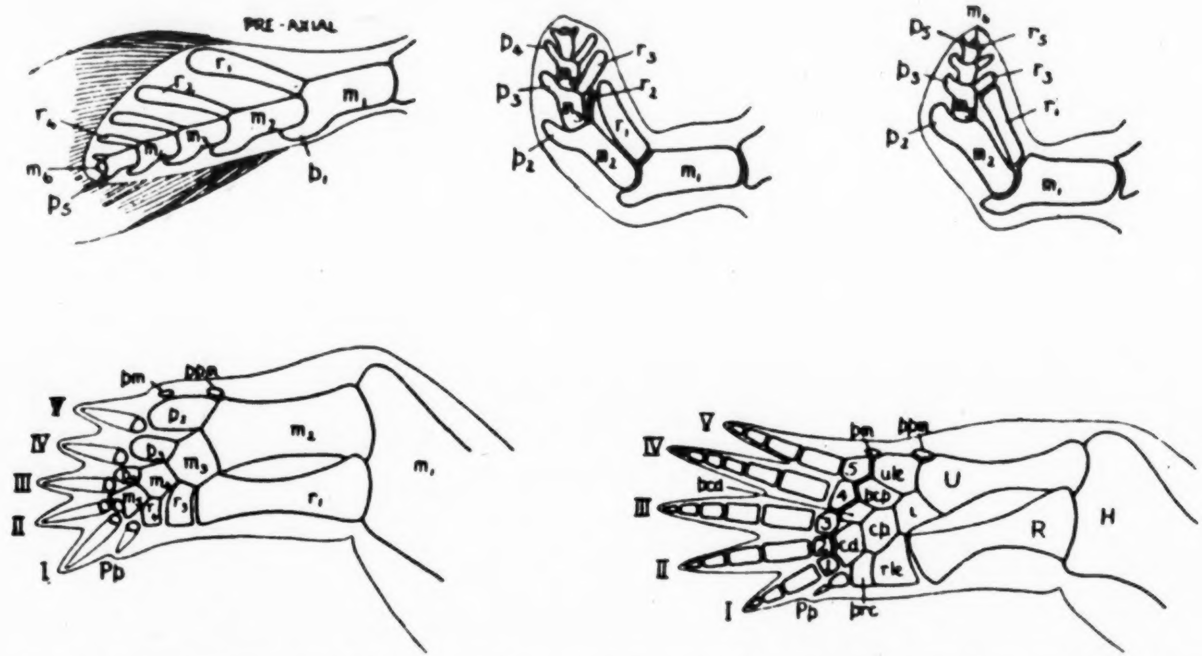

FIG. 6. How the osteolepid pectoral fin skeleton could give rise to the tetrapod fore-limb. Upper row, left to right, left pectoral fin in extended position (from above), to be bent forward to "walking" position, and with element "r_2" suppressed: Below, osteolepid right "arm" from above, with digits developing (left) and primitive tetrapod arm (right).

attached to the inside of the dermal shoulder girdle; the pelvic girdle is a pair of small plates enclosed in the muscles of the abdominal wall, widely separated from the vertebral column. This point will be discussed later.

The axial skeleton in the crossopterygians and their allies is often ossified, and develops around a very thick notochord. This notochord tends to become constricted in tetrapods by the cartilages or bones of the skull and the vertebral components. The vertebrae of *Eusthenopteron* and many other osteolepids are composed of a number of ossified elements in each segment. They resemble very closely in many respects a type of vertebra found in many primitive amphibians, known as the rhachitomous type and characterised by a wedge-shaped lateral profile of the larger units of the centrum. In fact, *Eusthenopteron* has almost every characteristic of a rhachitomous vertebral column already developed. This is not the place to discuss the relationships of the various types of vertebrae seen in primitive tetrapods; suffice it to say that this proto-rhachitomous pattern can, without great difficulty, be regarded as a suitable prototype for the great majority of early tetrapods.

Associated with the vertebrae are ribs. Now all the early fishes in which we have fossil evidence of ribs, with the exception of some Crossopterygii, have a series of single-headed ribs which gradually converge as traced backwards and pass into haemal arches. They are in fact what are known as pleural ribs, and are found even in coelacanths and in lungfishes. Tetrapods, on the other hand, have two-headed ribs which develop in quite a different way and are not homologous with haemal arches. Such ribs are fully developed in all the early Stegocephalia, including *Ichthyostega*; and a most interesting feature is that they often have a hook or blade like expansion in their upper portion, overlapping the next behind. Jarvik has already described short bicipital ribs in *Eusthenopteron*; further material, prepared again by Miss Andrews, makes it reasonable to suppose that the short process of the rib extended obliquely outwards, backwards and upwards, and it may represent the hook-like or blade-like part of the rib in early tetrapods. Once again, there cannot be the slightest doubt of relationship.

Before too much was known of the fossil forms, the list of

characters by which tetrapods differed from typical fishes was enormous. But we have now seen that many features characteristic of tetrapods are already present, or clearly foreshadowed, in the rhipidistians. These include the nasal capsule, structure of cheek, palate and jaw, a good deal of the pattern of the skull-roof, vertebral structure, ribs and paired limbs. The transition from fish to tetrapod was far less violent than once it seemed. Several of the peculiarities of rhipidistia may reasonably be related to adaptation to a rather harsh environment. Many of these fishes lived in shallow waters impoverished in oxygen, sometimes partly silted up, dried out, or choked with vegetation. Fishes living to-day in somewhat similar conditions in the swamps of Africa or the Gran Chaco or drainage-basins in Australia use many devices to supplement oxygenation through the gills, and to migrate or aestivate when conditions became bad. Many Devonian fishes, from both direct evidence and the evidence of their descendants, had air-bladders branching from the back of the pharynx which could no doubt in some cases serve as lungs. There is evidence for this in the living lungfishes and in fossil coelacanths (though *Latimeria* has modified its heritage). There is thus some reason to suppose that "lungs" were present in rhipidistians; they may of course also serve as bouyancy-controlling devices in fishes.

The structure of *Eusthenopteron* suggests that it could have used its pectoral fins as powerful but clumsy arms for dragging itself along on the bottom of a lake or stream and for getting over short distances of sandbanks or mudflats. The pelvics, however, could not have borne much load, as this would compress the abdominal contents between the girdle and the vertebral column. A fish in water is supported bouyantly and uniformly; when it leaves the water its effective weight is greatly increased. The upward growth of the girdles so that the pelvic girdle meets the sacral region, and the double-headed dorsal ribs, can be shown to be elegant ways of supporting the weight of the body of a tetrapod on the pillars provided by the legs and the cantilever-beam provided by the vertebral column and ribs. It is quite easy to show that pleural ribs as found in most fishes cannot help to support this cantilever, while dorsal ribs can.

Again, the head of the fish in water needs no special support.

Out of water, it is effectively immensely heavier. Yet to survive the animal must eat, and the face and jaws must be maintained; but the brain-case is shortened and the occipital surface fully defined in tetrapods, bringing as much as possible of the load close to the neck-joint. The remarkable proportional changes of the skull correlate with this. It is not therefore very difficult to see that the loss of bouyancy when primitive tetrapods left the water explains fully the necessity of many of the structural modifications.

By the same tokens, it would seem that *Eusthenopteron* and its allies had already to some extent adapted themselves to similar conditions, so that they could escape bad conditions and seek fresher waters. Indeed, one of the most engaging paradoxes in the whole situation is that the tetrapod state, from which the conquest of land and air has taken its course, arose in all probability as a more efficient means of ensuring that an essentially aquatic life could be pursued even when local conditions became too difficult.

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EXHIBITS IN THE LIBRARY

A display of fossils of fishes and primitive land animals, arranged by *Professor T. S. Westoll* including some lent by *The Director, British Museum* (*Natural History*) and *Professor D. M. S. Watson*

COSMIC RAYS FROM THE SUN

By M. A. ELLISON, Sc.D., F.R.A.S., F.R.S.E.
Senior Professor of Astronomy, Dublin Institute for Advanced Studies and Director of Dunsink Observatory

Weekly Evening Meeting, Friday 27th October, 1961

W. E. Schall, B.Sc., F.Inst.P.
Treasurer and Vice-President in the Chair,

The kindly shine of summer, when tracked home with the scientific spy-glass, is found to issue from the most portentous nightmare of the universe—the great conflagrant sun: a world of hell's squibs, tumultuary, roaring aloud, inimical to life.

Robert Louis Stevenson, *Pan's Pipes*

Stevenson wrote these lines at a time when the study of solar activity was in its infancy: yet every word he uses has high significance in our present knowledge of the conflagrant sun and its influence upon the earth. We need only substitute a few technical terms—for example, flares are hell's squibs, convection currents the tumult, shock waves (i.e. sound waves) are roaring aloud, and X-rays and high-energy particles are inimical to life—in order to obtain our working picture of the active sun.

The quiet sun—a ball of gas nearly one million miles in diameter—provides us with all our heat and light, maintaining our life on earth by the storage of solar energy in the growth of plants. But the active sun does its best to upset our balance: in its hot, turbulent outer layers catastrophic events take place. These events—the solar flares—have immediate repercussions in our terrestrial atmosphere ninety-three million miles away.

We have found that flares emit radiation of two types, both waves and particles. In the race from the sun to the earth both start together, during the flash of the flare; but the waves, travelling with the speed of light, win by a comfortable margin. Whatever their wave-length may be, the travel time is the same for all, namely $8\frac{1}{2}$ minutes; consequently all the waves reach the earth at the same moment—the instant when we see the flare flashing up in the field of view of our hydrogen filters. Among these wave radiations we recognise three main types, in order of increasing wave-length—X-rays, visible light and radio waves.

The particles lag behind, and arrive at various intervals depending upon their speeds. At the present time we recognise three different groups of particles which are accelerated by flares. One group, which we refer to as the magnetic storm particles, reaches us some 20–50 hours after the flare. These are clouds of solar gas, consisting mainly of ionized hydrogen atoms (protons) and electrons. A gas of this kind, being composed of electrically charged particles, we speak of as a plasma: it has very different properties from those gases we are familiar with on the earth that are made up of neutral atoms and molecules. The particles of the plasma are guided by the earth's magnetic field, and being of low energy they enter our atmosphere in the region of the two magnetic poles, spiralling in along the lines of force. Here they set up powerful electric currents, flowing in the conducting layers of the ionosphere, and the magnetic disturbances due to these currents are known to us as magnetic storms.

The same particles, by causing excitation of atmospheric atoms and molecules, lead to the dancing, colourful displays of the aurora polaris: this is the one terrestrial effect of a solar flare which is visible to the world at large and needs no complicated apparatus to behold.

A second group of particles reaches us with a delay time of the order of 1 hour or more. These are mainly protons having energies within the range 10–400 Mev* and we must regard them as coming within the category of those high-energy particles which we speak of as cosmic rays. Their energies are such that they enter the atmosphere in locations within 30° of the two geomagnetic poles. Here they give rise to intense ionization in the *D*-region of the ionosphere, and one of the principle results of this ionization is the production of polar cap black-outs of the incoming cosmic radio noise in the VHF band. These solar protons have insufficient energy to penetrate to the lower levels of our atmosphere, nor do they generate any secondary particles which can be recorded at ground level. So far, they have been studied directly only from high-flying balloons and indirectly from the absorption effects for radio waves which their ionization produces in the polar regions.

*1 Mev is one million electron-volts: one electron-volt is the energy gained by an electron in falling through a potential difference of 1 volt.

On rare occasions, however, some of the greatest (3+) flares accelerate into space showers of protons which are endowed with much higher energies: these energies lie in the range 1–100 Bev*. Such great particle energies are comparable with those of the galactic cosmic rays which have long been known to bombard our atmosphere.

The primary cosmic rays, wherever they come from, consist of positively charged atoms traversing space at speeds which approach the velocity of light. They appear to encounter the earth with a uniform distribution, or nearly so, from all directions in space, and their energies lie within the range of 10^7 to 10^{19} electron-volts. As we might expect, the majority of these particles are protons—the nuclei of hydrogen atoms—hydrogen being the most abundant element in the universe, but among them there is also a small proportion of heavier atoms, up to atomic weight 56—that of iron.

When these high-energy particles arrive in the upper levels of the atmosphere they begin to perform a remarkable series of atom splitting experiments, colliding with the oxygen and nitrogen atoms, giving rise to nuclear explosions and producing secondary particles of many types, the effects of which can be traced downwards to ground level and even far below the surface of the earth. The two main types of secondary particle are the mesons and the nucleons (protons and neutrons). Mesons are particles having masses intermediate between those of the electron and proton. At least seven different varieties of mesons have been identified, some charged positively, some negatively and one that is neutral. All such particles have a life-time of one-millionth of a second or less, after which they decay spontaneously, giving rise to high-energy electrons, either positive or negative, to neutrinos, or to photons (γ-rays). The mesons have been recorded continuously at ground level for about 20 years, the neutrons since 1948. The meson monitors give their maximum response from original primary particles of energy about 10^{10} electron-volts, whereas the neutron monitor is most sensitive to primaries of lower energy, about 10^9 electron-volts.

During the past 20 years we have recorded 12 cases of sudden increases of cosmic ray intensity, as indicated by these two types

*1 Bev is one thousand million electron-volts.

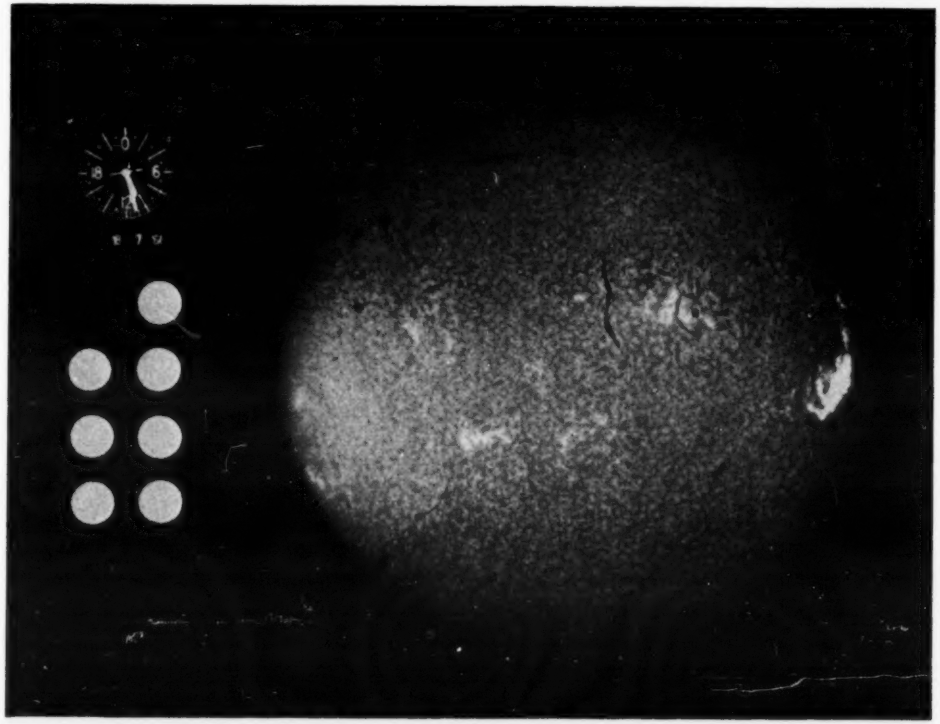
of apparatus located at ground level. The showers of primary particles responsible for these effects have come directly from the sun, and all have occurred shortly after the peak intensity of outstanding solar flares (Plate I). The travel times, that is the interval between the peak brightness of the flare and the arrival of the cosmic rays at the earth, have varied between 3 minutes and 1 hour.

Solar flares have assumed a unique interest since it became apparent some ten years ago that here we have a mechanism—the only one observable in the universe—where particles can be accelerated to relativistic energies (10^9 electron-volts for protons).

The energy released in such a flare is enormous—of the order of 10^{33} ergs—and there is much evidence that the release occurs in a matter of a few minutes, *i.e.* during the flash of the flare which is the most outstanding feature of the Hα light-curves. This amount of energy is greater than the entire heat energy stored up within the whole corona and chromosphere. It is clear, therefore, that the energy which is suddenly transformed in the flare cannot have been drawn in from the surrounding regions, but must have been stored up slowly *in situ*, almost certainly in the complex magnetic fields which always permeate the flare region above a large sunspot. The destruction of a magnetic field of 500 gauss in this area would supply the energy required, but how does it take place? We now recognise that the magnetic lines of force in the flare region are anchored in a plasma of ionised particles: the plasma is in a state of flux and it is the stability of this plasma which is the key to the whole problem. Any acceptable theory of the flare mechanism must explain the slow storage of energy in the plasma followed by its explosive release and conversion into other forms.

It would appear that about one per cent of the energy released in a flare is used up in the acceleration of high-energy particles. The basic mechanism is not yet fully understood, due to our ignorance of plasma physics on so large a scale. However, once the particles have left the flare region we can use them as probes to investigate the magnetic fields and the plasma clouds in interplanetary space. Herein lies the great interest of these sudden showers of cosmic rays issuing from a point source on the sun.

Light travels in straight lines, but this is not true of energetic



The Cosmic Ray Flare of 18th July, 1961 in W. longitude 60°. Photograph taken in hydrogen light with the Lyot heliograph at the Royal Observatory, Cape of Good Hope.

PLATE I

charged particles: they are guided by magnetic fields. In general the particle progresses along a helical trajectory wound round the guiding line of force. The gyroradius of the spiralling particle is proportional to its energy and inversely proportional to the strength of the field. For a particle of energy 10^9 electron-volts and a field of 10^{-4} gauss, such as might obtain in the sun-earth space, the radius of curvature is 300,000 km.

The whole of galactic space appears to be permeated by weak magnetic fields which are "frozen into" clouds of ionized particles and partake of their motions. The interplanetary space is no exception: in our local region round the sun we have, it seems, a chaotic system of ion clouds. These are formed of material which is being blown out more or less continuously from solar active regions, the so-called "solar wind", and since the solar magnetic fields are bound into these clouds from the start they must be carried out along with them into space. We may regard such lines of force as infinitely extensible rubber strings, stretching out beyond the earth's orbit, twisting and turning in disordered fashion through the clouds that carry them, but eventually returning to the sun. Conditions in this interplanetary medium must vary greatly with the state of solar activity, the fields being stronger and more complex during the maximum period of the 11-year cycle.

Now, let us superimpose upon this picture the evidence which has become available from the dozen big showers of solar cosmic rays that have been registered by meson and neutron monitors at ground level, since the first recorded event of this kind on February 28th, 1942.

When we plot the positions of the cosmic ray flares upon the solar disk we find a most remarkable distribution. Seven have been located on, or near, the W. limb and none have occurred nearer than 75° to the E. limb. Class 3 and 3+ flares in general, disregarding their cosmic ray production, are distributed quite uniformly in regard to the sun's central meridian. In a survey of some hundreds, exactly half were found lying east of the C.M. and half west of it. But the cosmic ray flares show a strong longitudinal asymmetry. This great preponderance in the western hemisphere can only mean that there is a greater probability that the cosmic rays accelerated into space by a flare west of the central meridian

will reach the earth and produce ground level effects: easier and more direct trajectories evidently exist for high-energy particles when the source points are near the W. limb of the sun. We also find that the particle travel times (cosmic ray maximum *minus* flare maximum) are shorter for the flares in the western hemisphere.

Remembering that high-energy particles are guided to their destinations by magnetic fields, we can say that there must exist at these times a radial magnetic field in the sun-earth space and that the lines of force along which the particles spiral in towards the earth are bent by the solar rotation convex to the west.

The particles arrive from the direction of the sun, but once they come under the influence of the earth's magnetic field they are bent into complicated Störmer orbits, depending upon their energies and their directions of travel relative to the earth's magnetic axis: impact zones are established at places on the earth's surface where the intensities may be much greater than elsewhere. There are now sufficient cosmic ray monitors in operation round the world to determine the positions of these impact zones for each event, and it is then possible to compute back and to find the direction of the original trajectories before they entered the earth's field. This has been done for many of the showers: they have all been found to approach the earth from a limited region of the sky containing the sun.

If our eyes were sensitive to cosmic rays and we were observing from just outside the earth's magnetic field, we would first see a blaze of light in the solar direction, or to the west of the sun. Fifteen minutes to half-an-hour later the light would fill the whole sky: the early arriving particles come direct from the sun, but those which arrive later come uniformly from all directions in space. These late arrivals must have been bent and scattered by the action of disordered magnetic fields much further out beyond the earth's orbit. As we have seen, the acceleration of the particles takes place during the flare flash and this is probably all over within a few minutes; yet, the cosmic rays have in some cases continued to arrive at the earth for as long as 24 hours after the flare has died away. These facts provide the strongest evidence for the trapping and storage of the particles in the interplanetary magnetic fields.

These interplanetary fields also act in a remarkable way to modify the "constant" incoming flux of galactic cosmic rays.

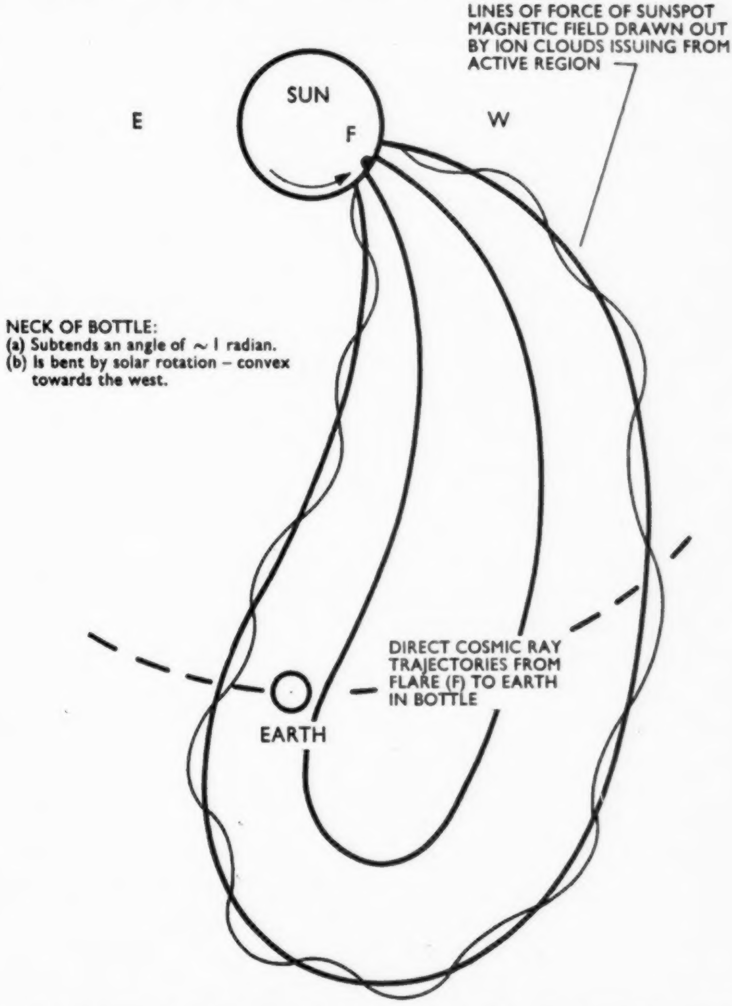


FIG. 1. The earth trapped inside a magnetic bottle. The bottle provides direct trajectories for cosmic ray particles from a flare near the W. limb to the region of the earth; it also partly shields the earth from the entry of outside cosmic rays coming from the galaxy.

At the time of the sudden commencement of a magnetic storm, when the earth becomes enveloped in a cloud of solar gas, there

is often a sudden decrease of cosmic ray intensity, as indicated by neutron monitors, and to a lesser extent by meson detectors, at ground level. The primary particle radiation reaching the earth at these times may undergo a reduction of as much as 30 per cent and may not return to normal for 10 days or more. This phenomenon is known as a Forbush decrease.

It would appear that under these conditions the earth is trapped inside what we may describe as a "magnetic bottle" (Fig. 1). The bottle is formed by lines of force which are drawn out into space from a sunspot region by the issuing clouds of storm particles. After about a day the elongating bottle encloses the earth and it continues to expand outwards into interplanetary space. When the earth is enveloped in the bottle it is shielded from the normal cosmic ray flux entering from the galaxy, and those particles of lowest energy are found to suffer the greatest reduction of intensity. This is the most outstanding example of the modulation of cosmic rays by magnetic fields of solar origin.

Furthermore, when the earth is inside a bottle and a solar flare occurs within the neck of the bottle, we obtain the best conditions for the direct propagation of the flare-accelerated cosmic rays across the sun-earth space. If we assume that the neck of the bottle is bent by the solar rotation convex towards the west and that, at its point of anchorage in the sun, it subtends a solid angle of about one radian, we have a model which will explain in general terms the longitude asymmetry which is so characteristic of the cosmic ray producing flares.

The galactic cosmic rays also show large changes in their energy spectrum between the times of sunspot maximum and minimum activity. In the energy range 1–50 Bev we obtain more than twice as many primary particles in the minimum years of the eleven-year cycle as at the maxima; the primaries of high energy are less affected than those of low energy. According to our present picture this appears to mean that when the sun becomes quiet the magnetic field structure in the solar system settles down into a simpler and weaker pattern. Under these conditions there is greater freedom of entry for the low-energy cosmic rays coming from the galaxy, and it may be only then that we receive the full unmodulated galactic flux.

The origin of cosmic rays has remained a great mystery since

their discovery in the early years of the present century. It used to be thought, following the ideas of Fermi, that the particles gained their energy by collisions with magnetised ion clouds in the galaxy—moving plasmas, as we would now call them—and that the particles were accelerated by a process equivalent to the equipartition of energy. The discovery that the sun accelerates into space particles with energies as high as 10^{11} electron-volts suggests that we must now seek for the origin of cosmic rays in specific astronomical bodies, such as the atmospheres of flare-active stars, in supernovae explosions and in objects like the Crab nebula where powerful magnetic fields, anchored in turbulent, unstable plasmas are known to exist.

If we regard the sun as an "average star" in regard to its cosmic ray output we can calculate the total injection of cosmic rays into the galactic space from stellar sources. This turns out to be too small by a factor of a million, but there may well be special types of star whose atmospheres are much more flare-active than that of the sun. We also have to account for the acceleration of the very high-energy particles, up to 10^{19} electron-volts, to which the solar showers make no contribution. Again, we know relatively little about the containment of the high-energy particles within the galactic magnetic fields. Are all the particles we receive generated within our own galaxy, or can they cross the inter-galactic spaces and reach us from more distant sources in the universe, such as the colliding galaxies which are also powerful transmitters of radio waves?

These interesting questions are being posed and discussed by many workers whose contributions cannot be acknowledged in so short a review. A special tribute, however, must be paid to the work of Professor J. A. Simpson of Chicago. By his development of the neutron monitor and his establishment of these recording instruments all over the world in preparation for the International Geophysical Year he has made a unique contribution to the study of solar cosmic rays. The new field of work he has opened up we now call "high-energy astrophysics".

EXHIBITS IN THE LIBRARY

A display of models, photographs and diagrams illustrating cosmic rays from the sun, arranged by *Professor M. A. Ellison.*

MODERN RESEARCH ON THE SKIN OF MICE AND MEN

By W. S. BULLOUGH, D.Sc.
Professor of Zoology, Birkbeck College, London

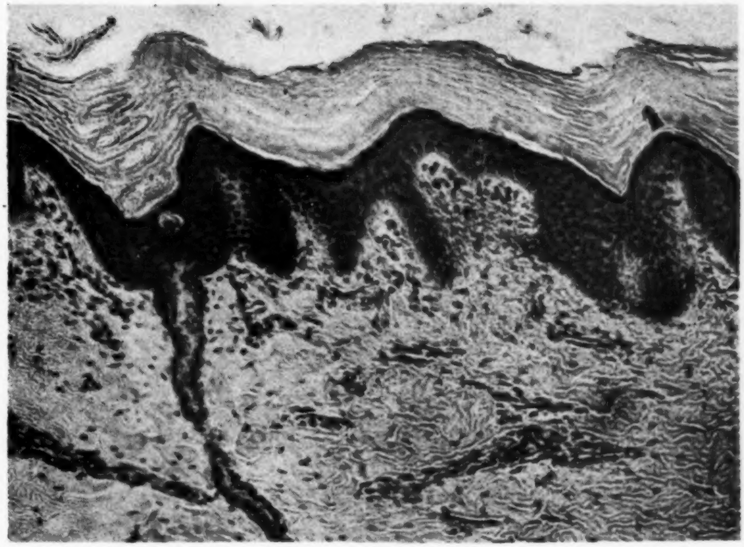
Weekly Evening Meeting, Friday 10th November, 1961

Wing Commander H. F. Tiarks, F.R.A.S.
Vice-President in the Chair

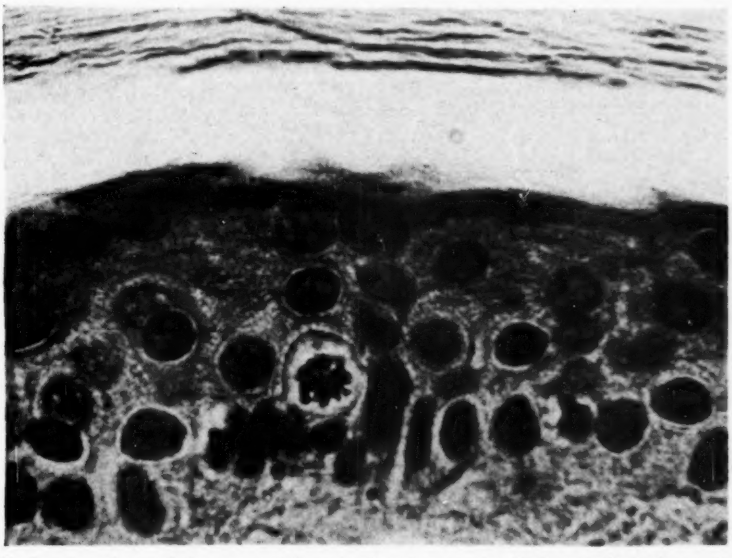
RECENT years have seen a greatly increased interest in mammalian skin, and notably in the skin of mice and men. There have been considerable increases in our knowledge both of skin structure and of skin function, but here it is proposed to concentrate on only one aspect of this field of research, namely the nature of that mechanism which controls the rate of cell replacement in the epidermis. This research is of particular interest because the results that have been obtained and the conclusions that can be drawn may shed considerable light on the whole important subject of the control of cell division in adult mammalian tissues, including those of men. This whole subject has recently been reviewed at length (Bullough, 1962).

In man the epidermis forms an exceedingly thin layer over the whole body, being mostly about 1/250 inch thick but increasing to about 1/25 inch thick on the palms and on the soles of the feet (Plate IA). Its outer part is dead but its inner part is composed of several layers of living cells. However, in spite of its thinness it is the dead outer part of the epidermis that forms the main barrier between the living tissues within and the physical and chemical hazards of the world outside. Being formed of the tough protein keratin, it is very resistant to abrasion. It is also resistant to penetration by many chemicals and by most bacteria and fungi, and it is waterproof to prevent undue water loss.

However, it is mainly because of abrasion that the dead outer surface is constantly being worn away, and this loss must be made good by the multiplication of the cells at the base of epidermis (Plate IB). Thus there is a constant slow flow of cells outwards through the epidermis. During this journey the cells manufacture keratin within themselves, they die to form a part of the outer dead layer, and ultimately they are lost from the outer surface. Although this type of differentiation is typical of the epidermis,



A. Section through human sole of foot showing the two layers of epidermis, the inner of living cells and the outer of dead, flattened and keratinised cells. On the left is the opening of a sweat gland.



B. Section through human epidermis showing a mitotic figure. It is through mitotic division that new cells are produced to make good the cell loss from the surface.

PLATE I

the method of cell replacement based on cell division, or mitosis, is almost universal in the tissues of the body. However, the rate at which cells wear out, die and are replaced is very different in different tissues. Examples of tissues with an exceedingly high rate of cell replacement by mitosis are growing hair roots, the living mucosa of the stomach and intestine, and the bone marrow which produces new blood cells. In man it is said that the entire stomach lining is replaced every two days, and that some ten million new red blood cells are produced each second. At the other extreme, examples of tissues with a very low rate of cell replacement are those composing such organs as the liver, kidneys and pancreas.

Different as the various body tissues may be, it is important, first, to remember that in studying the manner of cell replacement in the epidermis we are also studying the manner of cell replacement in the whole body, and second, that this highly important process is also potentially a highly dangerous process. If the control of mitotic activity is broken in any corner of the body the result is cancer.

In studying mitotic activity and mitotic control it is, of course, necessary to use experimental animals such as mice. In them the epidermal mitotic rate can be investigated either by removing small pieces of skin at intervals from mice treated in various ways, or more precisely by incubating small pieces of skin in a saline medium to which can be added a variety of test substances such as hormones.

Studying epidermis taken from normal mice the first and most obvious conclusion to be drawn is that the rate of cell replacement is not constant but fluctuates from hour to hour. The pattern of fluctuation is similar day by day and it forms the well-known diurnal mitotic cycle. An analysis of the cycle in the mouse has shown that cell replacement is low while the animal is awake and active and high while it is quietly resting or asleep. An essentially similar cycle has been described in man but owing to the considerable difficulties of getting samples of skin from normal people who continue to act normally throughout the whole twenty-four hours, the figures are much less reliable.

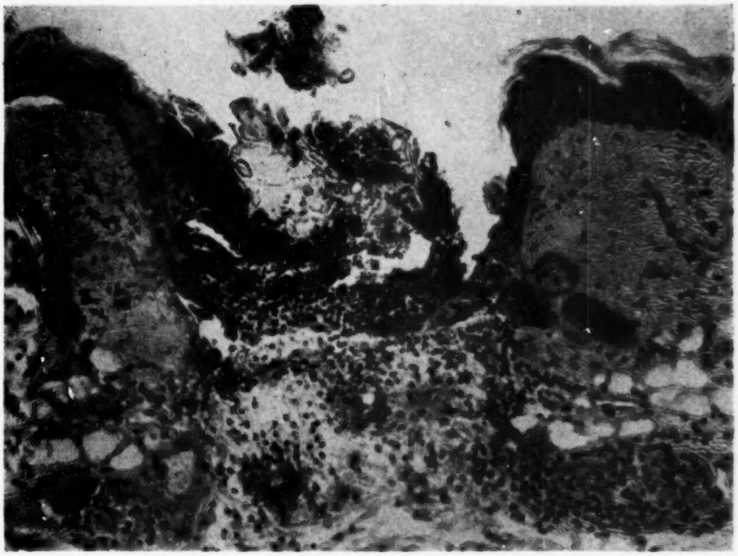
A great many diverse physiological changes occur in an animal when it goes to sleep, and determining which of these may under-

lie the changes in the behaviour of the epidermal cell has proved to be a long and difficult task. However, it is now known with reasonable certainty that at any one time the epidermal mitotic rate is a function of the degree of nervous stress then being felt by the animal. Obviously when a mouse is awake and active it is subject to far greater stress than when it is quietly asleep, and the difference shows, for instance, in the level of adrenalin in the blood. The greater the degree of stress, the more active the adrenal glands, and the higher the secretion rate of adrenalin. Adrenalin is a powerful inhibitor of many physiological processes, and it has also been shown to inhibit cell division. In an adult mouse five millionths of a gram of adrenalin is all that is needed to reduce the rate of epidermal cell replacement almost to zero. Thus in a normal mouse the higher the rate of adrenalin secretion the lower the rate of epidermal mitosis.

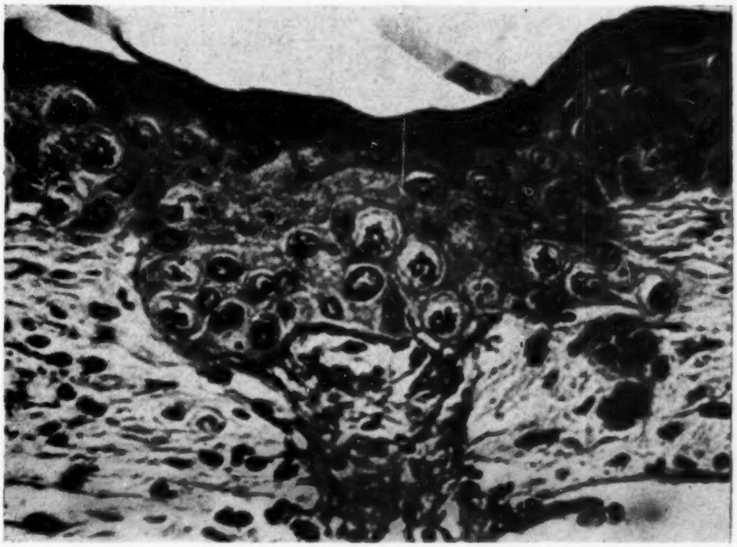
The most detailed analyses of the hourly rate of adrenalin secretion have actually been made in man, and it has been clearly shown that the maximum output occurs either during an emotional crisis or during violent muscular exercise. Far more adrenalin is produced during the day than during sleep at night, and in fact the diurnal cycle of adrenalin output is the exact inverse of the diurnal cycle of epidermal mitosis in men as well as in mice.

During a period of extra stress, induced for instance by forcing a mouse to stay awake for a few hours beyond its normal bedtime, or by making some sudden unusual disturbance such as a loud bang, the rate of epidermal cell replacement is abnormally depressed. It is interesting to note that this cell loss is fully compensated for in the subsequent sleep period when the mitotic activity is higher than during normal sleep (the rather complex reasons for this are discussed by Bullough and Laurence, 1961). Thus the inhibitory effects of extra short-term stress are quickly made good.

However, the effects of extra long-term stress may prove serious. In this connexion Steinberg and Watson (1960) have shown that the growth of young rats can be arrested by repeated stress induced in such simple ways as transfer to unfamiliar rooms and cages, changes in cage mates, and new kinds of diet. This effect may well be mediated through the increased secre-



A. Section through a small wound made two days previously in mouse skin. High mitotic activity has developed at the original edges of the wound, while the gap is being closed by migrating sheets of epidermal cells.



B. Section through a wound made five days previously in mouse skin. The wound has been covered by epidermal cells but the high mitotic activity has not yet died down.

PLATE II

tion rate of the adrenal glands, and notably through adrenalin.

While in a normal mouse the hourly rate of epidermal cell replacement may be determined primarily by the secretory activity of the adrenal glands, in abnormal circumstances another type of mitotic control mechanism becomes apparent (Plate IIA, IIB). It is well-known that less than 24 hours after the epidermis is wounded an abnormally high rate of epidermal cell replacement begins in the narrow zone immediately adjacent to the wound. Bullough and Laurence (1960a) have shown that, largely irrespective of the size of the wound, this highly active zone always has a width of about 1 mm., both in mice and men. The important points about the mitotic activity in this narrow zone are first that it is so very high (about 10 times normal) and second that it shows no diurnal cycle. The fact that the mitotic rate is not depressed when the mouse is awake may be taken to indicate that the cells have become relatively insensitive to the inhibitory action of adrenalin, and this can be confirmed by injections of adrenalin.

However, it is still possible by the imposition of excessive stress or by injections of relatively high doses of adrenalin to depress the mitotic activity adjacent to wounds, and this gives point to recent comments on the necessity for making hospital conditions more humane. In addition to the stressful effects of the alien hospital environment, a recent report approved by the Central Health Services Council has commented that "it is becoming progressively more difficult to rest in hospital and it is no longer unusual to hear of patients talking about 'going home for a rest'." Quite apart from the inhumanity of such a system, it is, on present evidence, the worst possible environment in which to try to effect a cure or to heal a wound.

To return to the phenomenon of the high mitotic rate adjacent to a wound, the commonest explanation is that the wound itself releases a mitosis-stimulating hormone, the so-called "wound hormone". There are several reasons for doubting this explanation and not the least is that after some forty years of effort to extract this "hormone" no success can be claimed. Experiments have therefore been performed in an attempt to discover whether this high rate of cell production can be ascribed not to the stimulus of a locally produced "hormone" but to the breakdown in wounded epidermis of some mitotic control mechanism that is

present in normal epidermis. In short the question is whether the high mitotic rate is due to the presence of some stimulant or to the absence of some inhibitor.

These experiments, done on the ears of mice, have been described in detail by Bullough and Laurence (1960a), and the following conclusions can be drawn. First, there is evidently no such thing as a mitosis-stimulating "wound hormone", the rise in mitotic activity being due in fact to the disappearance of a normally present mitotic inhibitor; second, the mitotic inhibitor which normally limits the rate of cell replacement in the epidermis is epidermis-specific; and third, the epidermal inhibitor is most probably produced by the epidermal cells themselves.

There are thus at least two systems which, acting as inhibitors, control the rate of cell division in epidermis, the one hormonal and emanating from the adrenal glands and the other also an internal secretion and emanating from the epidermis itself. It is obviously extremely important to discover whether similar mechanisms control the mitotic rates in other body tissues and evidence in the literature suggests that this may well be the case in such organs as the liver, the kidney and the adrenal itself. In the skin it also seems to be true in one of the inner layers known as the hypodermis (Bullough and Laurence, 1960b).

As mentioned already, the various tissues of the body show widely differing rates of cell production. It may be suggested that tissues with an extremely high mitotic rate, such as growing hair roots, may be lacking in their particular inhibitor, and it is interesting to notice that these tissues also appear to be insensitive to the inhibitory action of adrenalin and so show no diurnal cycle. At the other extreme, tissues which show no mitotic activity at all, such as resting hair roots, may produce a high concentration of their particular inhibitor, and again it is interesting to notice that adrenalectomy may result in the reappearance of mitoses (Mohn, 1958).

Evidence of this kind suggests that the local tissue inhibitor and the adrenal hormones may normally act together, and that neither may be able to exert its full action in the absence of the other. It may be for this reason that, although there may be a plentiful supply of the local tissue inhibitor, a fall in the rate of adrenal secretion in the less stressful conditions of middle age

leads to a considerable rise in the epidermal mitotic rate in both mice and men; conversely, although the secretion rate of adrenalin may even be higher than usual, a fall in the concentration of the local tissue inhibitor in the close vicinity of a wound also leads to a considerable rise in the local epidermal mitotic rate in both mice and men.

In hair roots there is a particularly fascinating situation which may prove to be dependent on a spontaneous oscillation between low inhibitor production, when the new hair grows, and high inhibitor production, when hair growth ceases.

The ideas set out above have an obvious bearing on the difficult and subtle problem of pathological growth. Obviously, when attempting to understand any pathological condition, it is essential to have as clear an idea as possible about the nature of the normal mechanism that has broken down. For this reason, research into the normal mechanisms of growth control should logically precede research into the effects of the breakdown of that control.

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EXHIBITS IN THE LIBRARY

Photographs and microscope slides showing the structure of the skin of mice and men, the method of cell replacement in both normal and wounded epidermis, and the cycle of changes in the follicle which lead to the production of a new hair.

The photographs were taken by *Mrs. H. Deol* and the exhibits were assembled by *Dr. E. B. Laurence*.

RESTLESS ATOMS IN SOLIDS

By DAME KATHLEEN LONSDALE, D.B.E., D.Sc., F.R.S.
Professor of Chemistry and Head of Department of Crystallography, University College, London

Weekly Evening Meeting, Friday 8th December, 1961

Mrs. L. Hawkes, M.Sc., F.G.S.
Vice-President in the Chair

THE most striking characteristic of a solid is rigidity which, however, is not simply a property of symmetry and periodicity of atomic arrangements, since the atomic arrangement in a glass is not a regular one. Rigidity is dependent rather on the fact that although atoms in every state of matter are moving, yet at sufficiently low temperatures the movements are not, in general, violent enough to cause the relative atomic positions to change. If, however, a crystalline solid contains imperfections, interstitial atoms, vacant sites, dislocations, impurities or grain boundaries, these may well move quite large distances even though local atomic movements are small. And although the mean atomic vibrational displacements are seldom more than 0.1–0.4 Å at room temperatures, yet occasional movements are much larger, and single atoms sometimes travel large distances in a solid. Different kinds of atoms or ions in a compound will vibrate with different mean amplitudes, and molecules undergo translational vibration, libration and some distortion. All these movements produce or affect so many physical and chemical phenomena that it is not possible to mention more than a selection.

Melting, softening and *crystal transformations*

Theory and experiment both show that atoms are not at rest even at O°K. They have zero-point energy. As the temperature is raised they also have thermal energy and this increases until the atomic vibrations are so large that the forces between the atoms can no longer keep the solid rigid in that particular arrangement. If the solid is amorphous it will soften and become a viscous liquid, but if it is crystalline then it takes up latent heat and melts, or it changes its crystal form. One of the more spectacular of such changes is the diamond $\rightleftarrows$ graphite transformation. Diamond begins to change to graphite when heated, in the

absence of oxygen, to upwards of 1500°C. Even at this temperature, however, theory indicates that the vibration displacements of the carbon atoms in diamond have a mean value of less than 0.1 Å, normal to any given plane.

At room temperatures the Na^+ ions in NaCl have a mean vibration displacement of about one-twentieth of the Na^+—Cl^- distance; that of Cl^- is a little less. But melting takes place when the ratio is about 1:6 (Cartz, 1955).

Thermal conduction and *thermal expansion*

A simple experiment shows that if a Cu rod is heated at one end, the increased atomic amplitudes are very quickly transmitted along the rod and the rod simultaneously expands. These two properties do not necessarily go together, however, for diamond conducts heat quite as well as aluminium, but it has a very small expansion coefficient at room temperatures. The expansion of organic crystals such as naphthalene or anthracene is not only anisotropic but many times (up to about 200 ×) larger than that of diamond.

For purposes of calculation of diffraction effects thermal vibrations in simple crystalline structures may be regarded in either of two ways: (1) as a superposition of a very large number of stationary patterns, in which the atoms are displaced from their mean, regular positions; (2) as a superposition of stationary simple harmonic waves. This only applies, however, when the substance is in a state of thermal equilibrium. If it is expanding then the vibrations must be anharmonic.

Volatility, solubility

At the surface of a crystal the molecules may be subjected to an unbalanced force. If so they will tend to fly off. This may be useful, as when the substance paradichlorbenzene, for example, is used to preserve blankets from moths. The molecules fly off the surface so fast that in a few hours exposed crystals will have disappeared completely. But in an X-ray tube, or in an electric light bulb, the emission of atoms from a hot W filament is a real nuisance. In the case of an X-ray tube it contaminates and reduces the characteristic radiation emitted and also increases the absorption of the window by covering it with a W film.

The function of thermal vibration in the process of solution of

a solid in a liquid is not so obvious. Atoms or molecules are removed from the surface of the solid and mingle with those of the solvent. In the case of $Na^+ Cl^-$ dissolving in water it is not difficult to see that a vibrating ion at the crystal boundary may easily form a temporary attachment to the polar water molecules, strong enough to detach it from the mother crystal. A somewhat similar process may function when anthracene, say, dissolves in an organic solvent; it is while thermal vibration has temporarily weakened its attachment to the main body of the crystal that a temporary attachment to a solvent molecule can suffice to remove it. Such an attachment could well occur most easily at the 9,10-carbon atoms which are the most reactive and also (Lonsdale and Milledge, 1959) the most mobile.

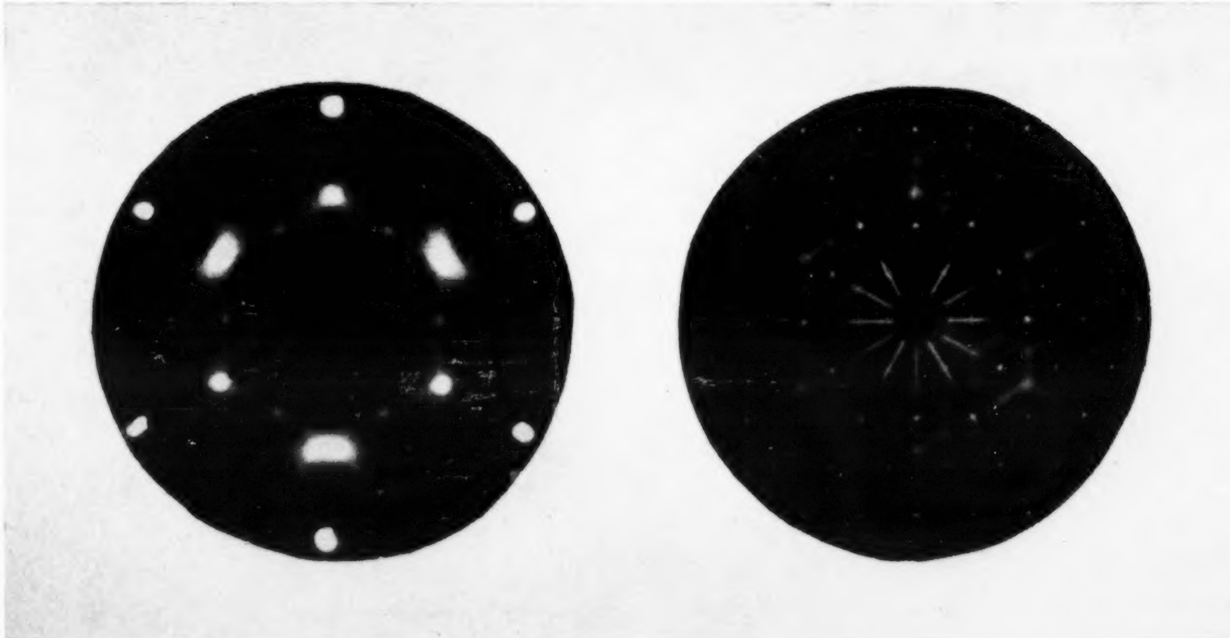
This would explain why it is that dianthracene, which has a crystal structure very similar to that of anthracene, is nevertheless insoluble in all light organic solvents. The molecules are twice as heavy; and their 9,10-carbon atoms are no longer "free" to form temporary attachments.

Movements at grain boundaries

The atomic vibrations at grain boundaries or in the neighbourhood of vacant sites will be larger than in the body of the crystal and therefore atoms will tend to make permanent movements of position more easily at these places. Impurities move to vacancies or grain boundaries and, if larger than the atoms of the matrix, they tend to get trapped there. Atoms tend to move across grain boundaries from a grain that is under strain to one that is not. This explains how it is that ice crystals at the bottom of a glacier are found to be very large relative to those at the top. The weight of snow or ice above imposes a strain on the ice crystals which form the glacier. Those in which this strain can be relieved by gliding grow (by transference of molecules across boundaries) at the expense of those less favourably orientated. The large crystals at the foot of the glacier are, therefore, so orientated that the basal (0001) layers, which define the directions of easy glide, lie along the direction of flow of the glacier (Perutz, 1953).

Annealing of radiation damage

Heat treatment will heal radiation damage in diamond; and it is probable that self-annealing is going on, during neutron



Left: Diffuse background on benzil photograph due to thermal vibration; temperature-dependent. *Right:* Diffuse background on trimethyl sulphonylmethane photograph (Abrahams and Speakman) due to ordered disorder; temperature-independent.

PLATE I

irradiation, simultaneously with the damage imposed. Laue photographs of diamonds which have had their density reduced by four per cent as the result of irradiation by fast neutrons show diffraction effects which are entirely similar to those produced by thermal vibration, except that they correspond to very much larger atomic displacements and that they are not temperature-sensitive. The random-rotation photographs of such irradiated diamonds show that *all* the unit cells are enlarged; it is not a case of a partly undistorted diamond containing regions of intense damage. There is no trace of diffraction spots at normal diamond spacings, and the spots due to the enlarged structure are sharp enough to show CuKα_1 α_2 separation. (H. J. Milledge, unpublished).

The nature of disorder in crystals

Any form of disorder which is completely random must give a diffraction effect similar to that of a gas; or if there are regions in the crystal where the disorder is essentially close-packed but amorphous, then its diffraction effect will be that of a liquid. Such effects are observed. But when diffraction effects are found which are not temperature-sensitive but which nevertheless show some symmetry and periodicity (related to that of the crystal) then the disorder cannot be random. It must affect every unit cell, or a definite proportion of the unit cells, in a partially ordered way. Such disorder may simulate thermal-vibration and cause an apparent increase of the Debye coefficients, but it will also cause a real variation of the thermal vibration, as compared with that in an ideal crystal, just as holes, impurities and other imperfections must do. (Plate I).

Solid-state diffusion. Ionic conductivity

Gold placed in close contact with lead diffuses into it very easily. Near to the melting-point of lead, the diffusion may be as fast as that of salt through water at room temperatures. Such diffusion can occur partly because Au atoms are smaller than those of Pb, partly because of the holes and dislocations in the Pb structure and partly because of the large thermal vibration in the Pb crystal, which allows rapid movement of vacant sites towards the common boundary where Au atoms are then trapped.

Sodium ions can easily migrate through glass. If an evacuated glass bulb is immersed in molten $NaNO_3$ and the evacuated space in the bulb is made conducting by emission of electrons from the hot W filament; and if a voltage is imposed between a copper anode in the molten $NaNO_3$ and the W filament acting as cathode, then a current will pass. The fact that the current is conducted through the glass by means of Na^+ diffusion is proved by the deposition of a Na layer on the inside of the glass bulb.

Similarly, it is stated that when yellow β-Ag_2HgI_4, which is tetragonal, changes at 46°C to red α-Ag_2HgI_4, which is cubic, the electrical conductivity is greatly increased. In the cubic form, the three (2Ag+Hg) ions randomly occupy four equivalent positions. There is therefore a random arrangement of one vacant site per unit cell and current passes mainly by means of the passage of Ag^+ ions one way and of vacant sites carrying an effective negative charge the other way.

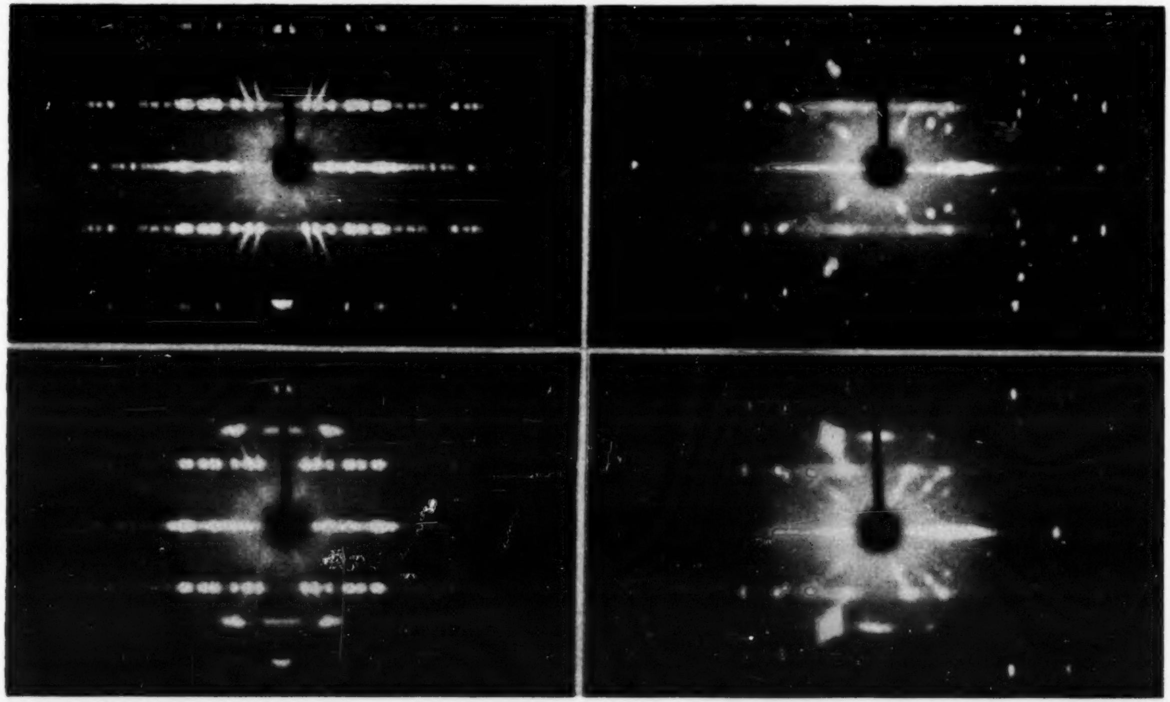
Generation of lightning movements of electric charge through ice subject to a thermal gradient

J. Latham and B. J. Mason (1961) have succeeded in explaining how it is that a sufficient quantity of charge separated by a large distance is generated, in a cumulo-nimbus thunder cloud, for a series of lightning flashes to occur. Soft hail pellets, falling at several metres per second through the cloud, will meet a fairly high concentration of small (say 0.1 mm diameter) supercooled water droplets. These freeze on to the surface of the hail, and subsequently, for each such droplet, about a dozen positively-charged tiny ice fragments are thrown off and are carried upwards taking their positive charge with them. The negatively-charged hail pellets continue to fall. Ingeniously-contrived laboratory experiments have shown that this process actually occurs and that the charge separation is such that within 20 minutes about 1,000 coulombs could be generated in a volume of 50 cubic kilometres.

The supercooled water droplets, in freezing onto the hail, give up latent heat and there is, therefore, a temperature gradient at the surface layers of the ice. The body of the hail may be, say, 10 degrees warmer than the exterior and where the ice is warmer the thermal vibrations will permit the formation of large numbers

I

II



III

IV

Top left I: Initial rotation photograph of the photo-oxide of anthracene (*b* axis). *Top right* II: Initial Laue photograph of the photo-oxide of anthracene, showing disorder layer lines corresponding to independent strings of molecules parallel to the *b* axis. *Bottom left* III: Repetition of I after 50 hours X-irradiation. Layer lines due to orientated anthraquinone appearing strongly; original layer lines weaker. *Bottom right* IV: Repetition of II. Laue pattern and layer lines of photo-oxide of anthracene disappearing. New Laue and layer lines appearing, due to anthraquinone.

PLATE II

of H^+ and OH^- ions. These diffuse to the colder surface, but the velocity of migration of the proton is perhaps ten times as great as that of the hydroxyl group. The actual proton movement is, in general, by transfer only along a single OH——O bond, with the formation of temporary $(H_3O)^+$ groups. This differential diffusion results in an accumulation of positive charge at the surface and the ejection of the positively-charged ice splinters.

Change of polarity of certain ferrite magnets as their temperature is changed

Ferromagnetism results from the interaction of the magnetic moments of atoms which have unbalanced spin orbitals; it is confined to crystals where there is, within certain limits, a definite ratio of interatomic distance to spin-orbital diameter. Sometimes the interaction is direct, sometimes it occurs through an intermediate anion such as O^{2+} (super-exchange), in which case both interatomic distances and metal-oxygen-metal angle may be important. Either of these may change with temperature and do, in fact, change continuously with thermal vibration, which opposes perfect lining up of the "atomic magnets" and which, above the Curie (or Néel) point is sufficient to prevent it altogether, leaving only paramagnetism.

In the spinels, there are two (or more) different kinds of metallic ions, which distribute themselves on two kinds of sub-lattices within the oxygen-ion framework. One sub-lattice (A) consists of small tetrahedrally-surrounded sites; the other (B) of larger octahedrally-surrounded sites. Magnetic atoms on A sites will line up with each other (AA^+ interaction) as far as thermal vibration will allow. So do those on B sites (BB^+ interaction). But there is a negative interaction between magnetic ions on A sites and those (which may be of the same or another element) on B sites (AB^- interaction). There is, in general, a resultant ferrimagnetism, that is, a preponderance of magnetic moment in one direction. Since, however, these interactions vary differently with temperature there may be a "compensation temperature" at which the magnetic spinel becomes an antiferromagnet and then, with further change of temperature, changes its polarity.

This occurs for a number of ferrites of which $Li_{0\cdot5}Fe_{1\cdot25}Cr_{1\cdot25}O_4$ is typical (Gorter, 1954). At room temperatures the

distribution of ions is as follows: on A sites $Fe^{3+}_{0.91}$, $Li^{+}_{0.09}$; on B sites $Li^{+}_{0.41}$, $Fe^{3+}_{0.34}$ $Cr^{3+}_{1.25}$, and it is probable that there is some local ordering of the metal ions within the respective sub-lattices. The compensation temperature is 38°C and the Curie point is 214°C. The rather large nonmagnetic Li^{+} ions, which also have relatively large thermal vibrations, will certainly be a disturbing factor, especially in the small A sites.

Solid-state chemical reactions

When the photo-oxide of anthracene  is heated to 160°C it shatters (Bender and Farber, 1952). If a single crystal is irradiated by X-rays at room temperatures, or even at low temperatures, it changes slowly, but in the end completely, into a single crystal of anthraquinone. Laue photographs show that the photo-oxide, even when freshly crystallized, does contain some chains of molecules parallel to the unique monoclinic axis which are detached from their neighbours and randomly orientated about that axis. The thermal vibrations of the two outer rings and of the oxygen bridge are very large and the bridge easily breaks; the hydrogen atoms are flung off and the molecules straighten out into anthraquinone, but without breaking up the structure entirely. Both structures are present in parallel at an intermediate stage (Plate II).

The photo-oxide of 9.10-diphenylanthracene behaves differently when heated. At 200°C it gives off all its oxygen and reverts to the pure hydrocarbon (Dufraisse and Gérard, 1935). It is evident that in this case the thermal vibrations, in breaking the bridge, cause the loss of O_2 rather than H_2, simply because the phenyl side-groups are too large and heavy to be thrown off and diffused out of the crystal. Diffraction experiments will be undertaken to see whether X-irradiation has a similar effect.

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RESTLESS ATOMS IN SOLIDS

EXHIBITS IN THE LIBRARY

(*a*) Demonstration and model illustrating the Brownian Motion, lent by *The Director, Science Museum.*

(*b*) Demonstration showing the effect of iodine on evaporated tungsten in an incandescent lamp, lent by the *G.E.C. Osram Lamp Division.*

(*c*) Models and photographs illustrating diffraction patterns from ice and the growth of ice crystals, lent by *Professor M. Blackburn* and *Professor B. J. Mason.*

LIBRARY CIRCLE MEETING

Thursday, May 4, 1961

THE FASCINATION OF MINIATURE BOOKS

By PERCY E. SPIELMANN,
Ph.D., B.Sc., F.R.S.L., M.R.I.

H. R. Rishworth, C.B.E., F.R.C.S., M.R.I., in the Chair

THE SPEAKER'S LIBRARY of miniature books consists of more than 500 volumes collected over a period of about 7 years and covering a wide range of subjects—bibles, psalms, prayers and instruction; the classics; literature of many nations; a large number of almanacs in series of years and from several countries; children's books; and a wide "coverage" of miscellaneous information. The books in the Library date from early in the sixteenth century. The Speaker explained that his limitation of size in the selection of the books for his collection was 3 and sometimes 3½ inches in height (as compared with the American standard of 4 inches). He also justified the existence of miniature books and explained that most of them can be easily read with an ordinary reading glass.

The book-cases in which the Library was kept were specially made for the main collection (Plate I). Other cases were used for housing the smaller sections. Small boxes were devised to form a double row of books on each shelf, and to hold those too small or too delicate to stand alone.

The famous Thumb Bibles (the earliest edition in this library being 1693) were initiated by John Taylor, who called himself "The Queen's Waterman" and "The King's Waterman". He was a turbulent propagandist, especially in favour of his "poor trade" against the hired "hackney-hell cart" that was ruining it; he published descriptions of travels in England and Scotland (where he was a guest of the Earl of Mar) and a number of religious books. The *Dictionary of National Biography* calls him a "literary bargee" and his publications coarse, brutal and contemptible.

The Library contains a large variety of Almanacs, which were controlled in this country by James I by the granting of monopolies for publishing almanacs to the two universities and to the Stationers' Company.

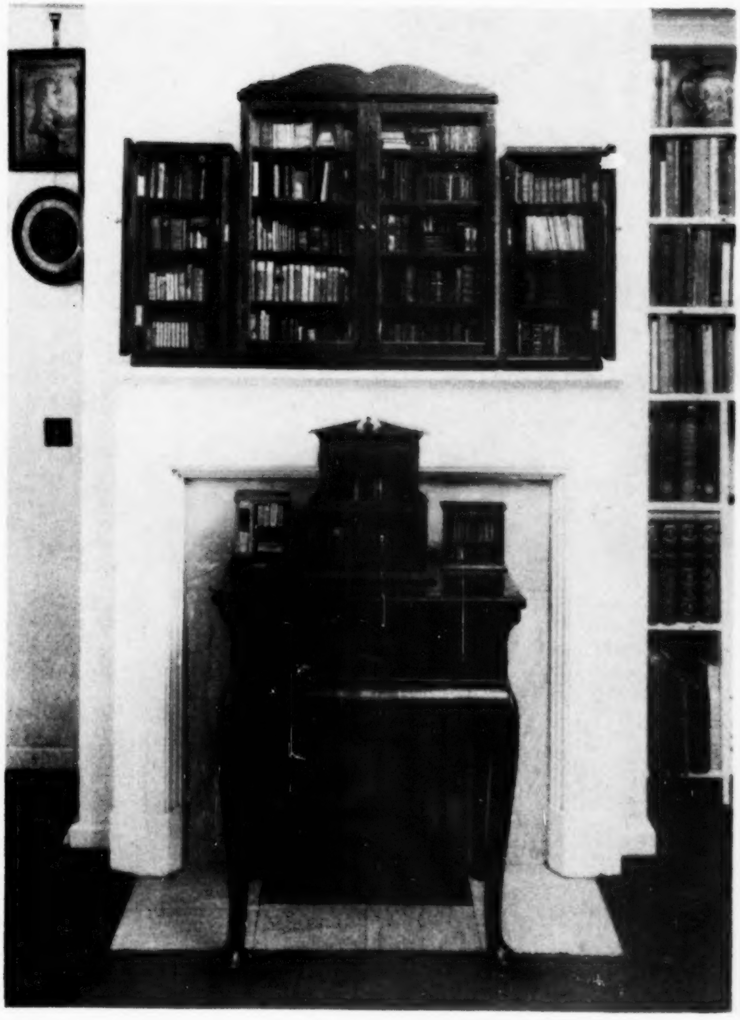
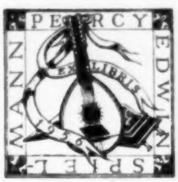


Plate I

In common with other printed matter a tax was levied on the publication of almanacs and this too caused great resentment throughout the trade. Thomas Carnan, a London bookseller and publisher, led the fight to break the monopoly of the Company of Stationers and, after repeated appearances before the magistrates, his vigorous attack achieved success, the monopoly being finally ended.

Many famous publishers and printers on the Continent produced miniature books, among them Plantin, Didot, and Elsevier. In this country there was Pickering, who introduced linen as a material for book-binding, and became famous through his collaboration with his supreme printer Corrall; and Bryce of Glasgow who produced tiny books by the million, one of which



⅞ inch

½ inch

FIG. 1. The two sizes of book-plates used by Dr. Spielmann for his books.

was his *Smallest English Dictionary*, which was dedicated to Mrs. Kendal, the actress, for her interest in tiny objects.

The Speaker went on to explain that miniature books had been printed in about 20 different languages and the printing presses were widely scattered over the world, one of the strangest being that of Djerba (an island off Tunisia) where a small Hebrew Prayer Book was printed about 1870.

The various techniques which were especially developed for the production of the tiny type-faces, the ink which would not clog, and the paper which would hold that ink were all described.

Among the lovely bindings and presentation cases in the Library there is a wonderful heart-shaped case in carved mother-of-pearl, containing a specially bound Schloss almanac of 1841, about 1 inch high, together with a folding lens, all bearing the initials P.R. It was doubtless a commemorative gift in connection

with the birth of Queen Victoria's first daughter, the Princess Royal, in the previous November.

Jones's Brilliant (type) Travelling Library of 42 volumes of English classics and poems (*c.* 1827) was shown and the Speaker described others which he knew dating from 1612 onwards. There were several curiosities also in this little Library, such as the illustration of the game of Diabolo, in a miniature French book of 1792; a tiny New Testament in the shorthand of Jeremiah Rich (*c.* 1665); and a humorous book on printing (size 5 x 4), in which has been inserted the same book in even more miniature form embedded in the hollowed-out blank pages at the end.

Music was often printed in the books of Psalms. One of 1626 explained the use of the U, Re, Mi, Fa, Sol system; in a Schloss Almanac of 1837 is an engraved Rondo from Balff's *The Maid of Artois*, which had been performed the previous May. Pickering's volume of *The Complete Angler* (1825) contains the Angler's song.

The association of book-plates with miniature books was touched on by the Speaker. He explained that he used two sizes of book-plates, $\frac{7}{8}''$ and $\frac{1}{2}''$ square (Fig. 1), in his Library and he urged a more general use of them.

Bibliography for miniature books in this country consists mainly of magazine articles—the German *Microbiblion* (1929), describing a Swiss collection since dispersed is the only "personable" volume, and the American *Bookmen's Bedlam*, by Blumenthal, contains interesting information. There is also the new American quarterly *The Miniature Book Collector* which began publication in 1960.

The catalogue of the Speaker's collection *Catalogue of the Library of Miniature Books collected by Percy Edwin Spielmann* published by Edward Arnold in 1961 (a copy of which was presented to the Library of the Royal Institution by Dr. Spielmann) contains full descriptions of over 500 miniature publications and much information about miniature books in general.

The talk was illustrated by lantern slides and a display of miniature books from Dr. Spielmann's Library.

FROM THE PROCEEDINGS OF 1861

This is Maxwell's famous discourse in which he first demonstrated in public the trichromatic nature of vision on which colour photography was subsequently based. He was only thirty years of age at the time and was Professor of Natural Philosophy at King's College London. The discourse was attended by 408 people. In all he gave three discourses at the Royal Institution.

Exactly one hundred years later on, 17 May 1961, Maxwell's demonstration, using copies of his original positives, was repeated in the Institution's Lecture Theatre by Dr. D. A. Spencer in the course of his Maxwell Centenary Discourse on *The First hundred years of colour photography*.

WEEKLY EVENING MEETING

Friday, May 17, 1861

THE DUKE OF NORTHUMBERLAND, K.G. F.R.S. President, in the Chair

PROFESSOR J. CLERK MAXWELL,

On the Theory of Three Primary Colours

THE speaker commenced by showing that our power of vision depends entirely on our being able to distinguish the intensity and quality of colours. The forms of visible objects are indicated to us only by differences in colour or brightness between them and surrounding objects. To classify and arrange these colours, to ascertain the physical conditions on which the differences of coloured rays depend, and to trace, as far as we are able, the physiological process by which these different rays excite in us various sensations of colour, we must avail ourselves of the united experience of painters, opticians, and physiologists. The speaker then proceeded to state the results obtained by these three classes of inquirers, to explain their apparent inconsistency by means of Young's Theory of Primary Colours, and to describe the tests to which he had subjected that theory.

Painters have studied the relations of colours, in order to imitate them by means of pigments. As there are only a limited number of coloured substances adapted for painting, while the number of tints in nature is infinite, painters are obliged to produce the tints they

require by mixing their pigments in proper proportions. This leads them to regard these tints as actually compounded of other colours, corresponding to the pure pigments in the mixture. It is found, that by using three pigments only, we can produce all colours lying within certain limits of intensity and purity. For instance, if we take carmine (red), chrome yellow, and ultramarine (blue), we get by mixing the carmine and the chrome, all varieties of orange, passing through scarlet to crimson on the one side, and to yellow on the other; by mixing chrome and ultramarine we get all hues of green; and by mixing ultramarine with carmine, we get all hues of purple, from violet to mauve and crimson. Now these are all the strong colours that we ever see or can imagine: all others are like these, only less pure in tint. Our three colours can be mixed so as to form a neutral grey; and if this grey be mixed with any of the hues produced by mixing two colours only, all the tints of that hue will be exhibited, from the pure colour to neutral grey. If we could assume that the colour of a mixture of different kinds of paint is a true mixture of the colours of the pigments, and in the same proportion, then an analysis of colour might be made with the same ease as a chemical analysis of a mixture of substances.

The colour of a mixture of pigments, however, is often very different from a true mixture of the colours of the pure pigments. It is found to depend on the size of the particles, a finely ground pigment producing more effect than one coarsely ground. It has also been shown by Professor Helmholtz, that when light falls on a mixture of pigments, part of it is acted on by one pigment only, and part of it by another; while a third is acted on by both pigments in succession before it is sent back to the eye. The two parts reflected directly from the pure pigments enter the eye together, and form a true mixture of colours; but the third portion, which has suffered absorption from both pigments, is often so considerable as to give its own character to the resulting tint. This is the explanation of the green tint produced by mixing most blue and yellow pigments.

In studying the mixture of colours, we must avoid these sources of error, either by mixing the rays of light themselves, or by combining the impressions of colours within the eye by the rotation of coloured papers on a disc.

The speaker then stated what the opticians had discovered about colour. White light, according to Newton, consists of a great number of different kinds of coloured light which can be separated by a prism. Newton divided these into seven classes, but we now recognize many thousand distinct kinds of light in the spectrum,

none of which can be shown to be a compound of more elementary rays. If we accept the theory that light is an undulation, then, as there are undulations of every different period from the one end of the spectrum to the other, there are an *infinite* number of possible kinds of light, no one of which can be regarded as compounded of any others.

Physical optics does not lead us to any theory of three primary colours, but leaves us in possession of an infinite number of pure rays with an infinitely more infinite number of compound beams of light, each containing any proportions of any number of the pure rays.

These beams of light, passing through the transparent parts of the eye, fall on a sensitive membrane, and we become aware of various colours. We know that the colour we see depends on the nature of the light; but the opticians say there are an infinite number of kinds of light; while the painters, and all who pay attention to what they see, tell us that they can account for all actual colours by supposing them mixtures of three primary colours.

The speaker then next drew attention to the physiological difficulties in accounting for the perception of colour. Some have supposed that the different kinds of light are distinguished by the time of their vibration. There are about 447 billions of vibrations of red light in a second; and 577 billions of vibrations of green light in the same time. It is certainly not by any mental process of which we are conscious that we distinguish between these infinitesimal portions of time, and it is difficult to conceive any mechanism by which the vibrations could be counted so that we should become conscious of the results, especially when many rays of different periods of vibration act on the same part of the eye at once.

Besides, all the evidence we have on the nature of nervous action goes to prove that whatever be the nature of the agent which excites a nerve, the sensation will differ only in being more or less acute. By acting on a nerve in various ways, we may produce the faintest sensation or the most violent pain; but if the intensity of the sensation is the same, its quality must be the same.

Now, we may perceive by our eyes a faint red light which may be made stronger and stronger till our eyes are dazzled. We may then perform the same experiment with a green light or a blue light. We shall thus see that our sensation of colour may differ in other ways, besides in being stronger or fainter. The sensation of colour, therefore, cannot be due to one nerve only.

The speaker then proceeded to state the theory of Dr. Thomas

Young, as the only theory which completely reconciles these difficulties in accounting for the perception of colour.

Young supposes that the eye is provided with three distinct sets of nervous fibres, each set extending over the whole sensitive surface of the eye. Each of these three systems of nerves, when excited, gives us a different sensation. One of them, which gives us the sensation we call red, is excited most by the red rays, but also by the orange and yellow, and slightly by the violet; another is acted on by the green rays, but also by the orange and yellow and part of the blue; while the third is acted on by the blue and violet rays.

If we could excite one of these sets of nerves without acting on the others, we should have the pure sensation corresponding to that set of nerves. This would be truly a primary colour, whether the nerve were excited by pure or by compound light, or even by the action of pressure or disease.

If such experiments could be made, we should be able to see the primary colours separately, and to describe their appearance by reference to the scale of colours in the spectrum.

But we have no direct consciousness of the contrivances of our own bodies, and we never feel any sensation which is not infinitely complex, so that we can never know directly how many sensations are combined when we see colour. Still less can we isolate one or more sensations by artificial means, so that in general when a ray enters the eye, though it should be one of the pure rays of the spectrum, it may excite more than one of the three sets of nerves, and thus produce a compound sensation.

The terms simple and compound, therefore, as applied to colour-sensation, have by no means the same meaning as they have when applied to a ray of light.

The speaker then stated some of the consequences of Young's theory, and described the tests to which he had subjected it:—

1st. There are three primary colours.

2nd. Every colour is either a primary colour, or a mixture of primary colours.

3rd. Four colours may always be arranged in one of two ways. Either one of them is a mixture of the other three, or a mixture of two of them can be found, identical with a mixture of the other two.

4th. These results may be stated in the form of colour-equations, giving the numerical value of the amount of each colour entering into any mixture. By means of the Colour Top,* such equations can

*Described in the Trans. of the Royal Society of Edinburgh, Vol. XXI., and in the Phil. Mag.

be obtained for coloured papers, and they may be obtained with a degree of accuracy showing that the colour-judgment of the eye may be rendered very perfect.

The speaker had tested in this way more than 100 different pigments and mixtures, and had found the results agree with the theory of three primaries in every case. He had also examined all the colours of the spectrum with the same result.

The experiments with pigments do not indicate what colours are to be considered as primary; but experiments on the prismatic spectrum shows that all the colours of the spectrum, and therefore all the colours in nature, are equivalent to mixtures of three colours of the spectrum itself, namely, red, green (near the line E), and blue (near the line G). Yellow was found to be a mixture of red and green.

The speaker, assuming red, green, and blue as primary colours, then exhibited them on a screen by means of three magic lanterns, before which were placed glass troughs containing respectively sulphocyanide of iron, chloride of copper, and ammoniated copper.

A triangle was thus illuminated, so that the pure colours appeared at its angles, while the rest of the triangle contained the various mixtures of the colours as in Young's triangle of colour.

The graduated intensity of the primary colours in different parts of the spectrum was exhibited by three coloured images, which, when superposed on the screen, gave an artificial representation of the spectrum.

Three photographs of a coloured ribbon taken through the three coloured solutions respectively, were introduced into the camera, giving images representing the red, the green, and the blue parts separately, as they would be seen by each of Young's three sets of nerves separately. When these were superposed, a coloured image was seen, which, if the red and green images had been as fully photographed as the blue, would have been a truly-coloured image of the ribbon. By finding photographic materials more sensitive to the less refrangible rays, the representation of the colours of objects might be greatly improved.

The speaker then proceeded to exhibit mixtures of the colours of the pure spectrum. Light from the electric lamp was passed through a narrow slit, a lens and a prism, so as to throw a pure spectrum on a screen containing three moveable slits, through which three distinct portions of the spectrum were suffered to pass. These portions were concentrated by a lens on a screen at a distance, forming a large uniformly coloured image of the prism.

When the whole spectrum was allowed to pass, this image was

white, as in Newton's experiment of combining the rays of the spectrum. When portions of the spectrum were allowed to pass through the moveable slits, the image was uniformly illuminated with a mixture of the corresponding colours. In order to see these colours separately, another lens was placed between the moveable slits and the screen. A magnified image of the slits was thus thrown on the screen, each slit showing, by its colour and its breadth, the quality and quantity of the colour which it suffered to pass. Several colours were thus exhibited, first separately, and then in combination. Red and blue, for instance, produced purple; red and green produced yellow; blue and yellow produced a pale pink; red, blue, and green produced white; and red and a bluish green near the line F produced a colour which appears very different to different eyes.

The speaker concluded by stating the peculiarities of colour-blind vision, and by showing that the investigation into the theory of colour is truly a physiological inquiry, and that it requires the observations and testimony of persons of every kind in order to discover and explain the various peculiarities of vision.

(J. C. M.)

PROCEEDINGS OF THE ROYAL INSTITUTION OF GREAT BRITAIN

Volume 38

1960–61

Containing accounts of the
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and other meetings

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